CHAPTER 1.
Introduction and Study Objectives

1.1 BACKGROUND

Legislation in New South Wales (Australia) requires coal mining companies to rehabilitate mined land to a standard at least equal to its pre-mining status, in terms of stability, aesthetic appearance and productive capability (Elliott *et al.,* 1980). For the majority of areas in the upper Hunter Valley, this means returning the land to an unimproved or semi-improved (e.g. fertiliser or seeding) grazing condition. Traditionally, this has been achieved by sowing exotic pasture grasses and legumes, and selectively establishing native trees and shrubs.

Topsoil is the most important factor in successful rehabilitation, particularly where the objective is to restore a native ecosystem (Koch and Ward, 1994). Most surface soils have far fewer limitations to plant growth than sub-soil material, and the additional cost of soil handling is generally outweighed by greater success in establishing vegetative cover. Ideally topsoil should not be stockpiled but should be lifted, transported and spread on a re-contoured area in one operation (known as direct return). Stockpiles can become anaerobic, soil structure deteriorates, organic matter and nutrients may be lost, seeds deteriorate, other plant propagules die and populations of beneficial soil micro-organisms are significantly reduced (EPA, 1995). However, weather conditions and the difficulties in timing rehabilitation to suit mining activity mean that at least some soil must be stockpiled for later use. If the topsoil must be stockpiled then it should be for as short a time as possible. Generally, stockpiles should be:

- As low as possible with a large surface area, designed to minimise the formation of anoxic zones;
- Revegetated to protect the soil from erosion, discourage weeds and maintain active populations of beneficial soil microbes; and
- Located where future mining will not disturb them, as excessive handling will adversely affect soil quality and increase the costs of rehabilitation (EPA, 1995).

Plants form beneficial symbiotic associations with a number of soil micro-organisms including fungi (mycorrhizae) and bacteria. Mycorrhizae are a natural component of the ecosystem in most Australian soils and are necessary for some plant species to become established. The majority of native plant species used in rehabilitation probably form associations with vesicular arbuscular mycorrhiza (VAM) and ectomycorrhizal fungi. The ability of VAM fungi to associate with plants is rapidly depleted by topsoil disturbance and stockpiling (Bell, 1996). This often results in low levels of infection in the early years of rehabilitation. Similarly, only a limited number of ectomycorrhizal fungi species have been observed in young rehabilitation. As a result, some species may not colonise in rehabilitated areas until specific mycorrhiza have recolonised. To conserve mycorrhizal inoculum, topsoils should be directly returned wherever possible and when stockpiling is unavoidable, the stockpiles should be low and revegetated as soon as possible.

Current Department of Infrastructure, Planning and Natural Resources (DIPNR) recommendations in the Hunter Valley specify that stockpiles should be constructed to a height of less than 3 m, based partly on the work conducted by Elliott and Veness (1985). However, compared to larger stockpiles, this often leads to a greater area of land being disturbed and an increase in the cost of constructing and managing topsoil stockpiles. An increase in the height of stockpiles would be beneficial to the Hunter Valley coal mines because of the often limited amount of land available for locating soil stockpiles within the active mining area.

While a number of authors have referred to the disadvantages of stockpiling topsoil from a physical, chemical and biological point of view, very few studies have actually quantified the potential deterioration that results from stockpiling. For example, Bell and Hannan (1993) stated that stockpiling for periods longer than about 6 months could cause structural degradation and death of seeds and micro-organisms. However, constructing dumps of minimum height and maximum surface area reduced the deterioration in quality. Seeding of the stockpile with a grass/legume mixture assisted in erosion control and reduced the loss of beneficial soil micro-organisms (Bell and Hannan, 1993). While few people would argue with the conclusions drawn, no reference was made to supportive data collected on this topic. The question is not really whether topsoil degrades or not, but to what extent and, furthermore, how can the process be minimised and, through best management practice, be rectified.

The impact that stockpiling topsoil has on the quality of rehabilitation depends on the final landuse. If the final landuse is a diverse native ecosystem, stockpiling topsoil is likely to have a large initial effect. For example, Koch *et al.* (1996) found that stockpiling of topsoil in the diverse jarrah forest ecosystem of Western Australia led to an 80 to 90% decrease in seed bank compared to 50% in directly returned soils. Bellairs and Bell (1993) recorded 10.5 seeds/m^{-2} in soil stockpiled for three years compared to 86.7 seeds m^{-2} in a fresh stockpile in topsoil utilised in mineral sand mining rehabilitation occurring in diverse heathlands in Western Australia. Furthermore, Jasper *et al.* (1998) demonstrated that rehabilitated bauxite mines in Western Australia that had topsoil directly returned exhibited greater microbial biomass than sites where topsoil had been stockpiled for the first 20 years following mining. Very few studies have actually investigated the potential deterioration in the stockpile itself and have instead focussed on what happens after the soil is respread in rehabilitated areas. It is important that the degree of degradation in the stockpile is known before the topsoil is respread as this will assist in identifying management options to ameliorate the topsoil (e.g. application of gypsum, use of cover crops) prior to or during the respreading operation. For example, where plant species are to be established quickly after reclamation, 5 cm of freshly stripped topsoil over respread, stored topsoil may act as a mycorrhizal inoculum (Thurber Consultants *et al* 1990).

Stockpiles have been shown to be anaerobic in nature, to cause a loss in organic matter, to disrupt microbial populations and to alter soil physical and chemical properties (Hunter and Currie, 1956; Miller and Cameron, 1976; Ross and Cairns, 1981; Schuman and Power, 1981; McQueen and Ross, 1982; Widdowson *et al.*, 1982; Anderson *et al.*, 1988). Only a relatively small number of papers have attempted to quantify degradation of topsoil in stockpiles. For example, McQueen and Ross (1982) studied the effects of stockpiled topsoils from opencast mining in New Zealand, focussing on the physical properties of soils. They reported that anaerobiosis occurred at a 2 m depth in 3 m high stockpiles and a relationship was identified between increasing aggregate size and anaerobic stability. This study concluded that stockpiling has a major effect on the physical condition of the soil resulting from soil compaction during the formation of the pile. An Indian study of managing topsoil to reclaim coal mining areas compared six different age classes of topsoil stockpiles to determine how much the soil had deteriorated over time and then compared the results to unmined areas (Ghose, 2001). Soil quality changes indicated a continuous, annual decrease that led to biological sterilisation. This indicates that rehabilitation of biological attributes is essential if the soil is stored for longer periods of time. These data, however, only take into account the top 0.2 m depth of topsoil collected from each stockpile. These studies have been useful in the development of methodology for the current research. However, many are outdated and have generally been carried out overseas. Therefore, they are only of minor relevance to open cut coal mining in the Hunter Valley.

Within Australia, very little research has been conducted to quantify the deterioration of soil quality in stockpiles, with the exception of Elliott and Veness (1985), Jenkins *et al.* (1987) and Anderson *et al.* (1988). Topsoil stripping and stockpiling of soils in the Hunter Valley has previously been reported to decline in structural attributes, with an increase in extractable phosphorus levels and in total nitrogen levels (Elliott and Veness 1985). The results suggested that improvements in the quality of stockpiled topsoil occurred over time in the upper layer of the stockpile (0-60 cm up to 2 years old). The authors suggested that storage of topsoil to optimise structural attributes and nutrient levels should not exceed this 60 cm depth. Jenkins *et al.* (1987) investigated the effects of storage for a period of 20 months on soil properties in the Hunter Valley. These authors reported an increase in bulk density of soil upon stockpiling, and observed a decrease in aggregate size and force required to disrupt peds of stockpiled soils relative to that of undisturbed soils, supporting the findings of Elliott and Veness (1985). Anderson *et al.* (1988) investigated topsoil stockpiling on two soil types (brown gradational and black earth soils) in the Bowen Basin in Queensland (Australia). Stockpiles of each soil were formed in both 'wet' and 'dry' seasons, and changes were monitored for three years using *in situ* devices in each stockpile. Laboratory analyses and glasshouse growth evaluated plant development on extracted stockpile cores and virgin soils. A wide range of properties were measured and failed to show any effects of time, depth of storage or water content on the physical properties of the black earth. Evidence showed that organic matter mineralised within the stockpiles, while gas analysis showed a tendency for the carbon dioxide content of the soil to increase with depth in the stockpile, indicative of increasing microbial decomposition of organic matter with depth. Gradational soils recorded differences in physical properties between the dry and wet stockpiles; aggregate stability declined with depth in the wet gradational soil stockpile, reported as a function of the mineralisation of organic matter. These studies emphasise the industry need for an updated study in the Hunter Valley. Similarities exist between the Bowen Basin study and the current Hunter Valley ACARP project. However, coal mining rehabilitation in the Hunter Valley represents a unique situation, as the quality of topsoil, from a physical, chemical and biological aspect, is often poor (refer to chapter 2 for more detail between the two areas).

1.2 PROJECT OBJECTIVES AND THESIS STRUCTURE

The major objective of this study was to examine the effect of increasing stockpile heights and age on the physical, chemical and biological components of topsoil used to rehabilitate open cut coal mines in the Hunter Valley, New South Wales.

The specific project objectives were to:

1) Identify possible techniques to construct and manage topsoil stockpiles by conducting a literature review on previous studies undertaken within Australia and overseas (chapter 3);
2) Conduct a preliminary survey of existing stockpiles at 12 mines in the Hunter Valley and compare stockpiling practices to the Bowen Basin (chapter 4);
3) Establish and monitor a field trial at three mine sites in the Hunter Valley to investigate the effect of stockpile height, age and depth on physical, chemical and biological properties of the topsoil (chapter 5);
4) Establish a glasshouse trial to propose practical ameliorative measures to address topsoil degradation following stockpiling in the Hunter Valley (chapter 6);
5) Establish and monitor rehabilitation field trials to investigate the amelioration of stockpiled topsoil through plant establishment and soil properties based on the results of the glasshouse trial (chapter 7);
6) Compare characteristics of sites rehabilitated with direct return versus stockpiled topsoil (chapter 7); and
7) Synthesise collected data and make recommendations on best practice topsoil management and rehabilitation techniques for the Hunter Valley (chapter 8).

This thesis is comprised of eight chapters constructed to illustrate rehabilitation and soil processes used to determine best practice topsoil stockpiling management. Following a brief introduction that outlines existing problems on topsoil management (chapter 1), the study region is described for the Hunter Valley and the Bowen Basin (chapter 2), where detailed information is presented on coal mining and rehabilitation procedures used in the Hunter Valley. A review of topsoil management in mining rehabilitation identifies knowledge gaps and possible techniques to construct and manage topsoil stockpiles from an international perspective (chapter 3). A comparison of topsoil stockpile characteristics between the Bowen Basin and the Hunter Valley is made (chapter 4) and, based on this initial study, stockpiles of different heights were constructed at three mines and monitored intensively over 30 months (chapter 5). A glasshouse experiment (chapter 6) was designed to identify suitable ways of ameliorating degradation that occurs during stockpiling. Based on these findings, a field rehabilitation trial was established using stockpiled soil from an earlier chapter and investigated a range of chemical and biological ameliorants to improve soil quality (chapter 7). Finally, a synthesis outlines practical guidelines that can be used to manage topsoil stockpiles in open cut coal mining rehabilitation sites in the Hunter Valley (chapter 8).

CHAPTER 2.
Study Site Description

2.1 LOCATION AND LAND-USES

The Hunter Valley is located 150 km northwest of Newcastle (Latitude: 32°55'00"S, Longitude: 151°45'00"E) on the lower north coast of New South Wales (Australia), and extends north west at an average width of 30 km (Figure 2.1). The Hunter Valley can be regarded as a true multiple landuse region with horse stables, vineyards, pastures, cropping land and coal mines located in close proximity to each other. A semi-rural environment supports 17 open cut coal mines that supply 58 Mt/year of coal for domestic and export markets (Figure 2.1 - Hannan and Gordon, 1996; NSWMC, 2001). The most extensive agricultural activity is beef cattle production that occurs on native and unimproved pastures. Dairy farming and lucerne production occurs on the alluvial soils of the Hunter River to the north (Hannan and Gordon, 1996).

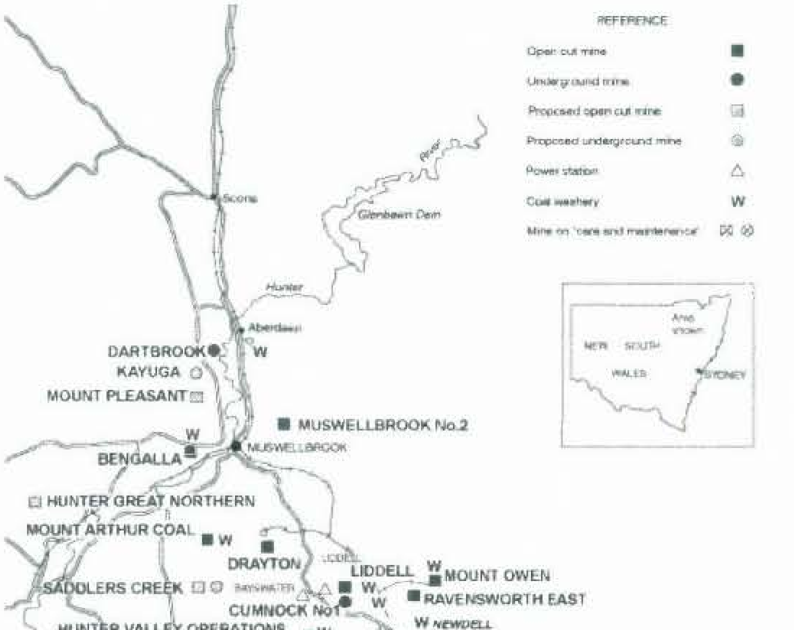

Figure 2.1: Location of the 17 open cut coal mines in the Hunter Valley, New South Wales.

2.2 CLIMATE

The climate of this region is warm temperate, with hot summers and cool winters. The average annual rainfall is 631 mm in the Singleton-Muswellbrook-Jerrys Plains triangle, with summer-dominant but winter-effective rainfall (Hannan and Gordon, 1996 - Figure 2.2). Effective rainfall can be in summer or winter months and does vary from year to year. This affects the timing of successful mining rehabilitation. Spring rains are followed by several months of hot, dry weather where the evaporation rate exceeds the rainfall. Mean monthly temperatures range from 10.3 °C in July to 23.3 °C in January, and up to 150 days of frost risk can occur each year between early May and early October (Hannan and Gordon, 1996).

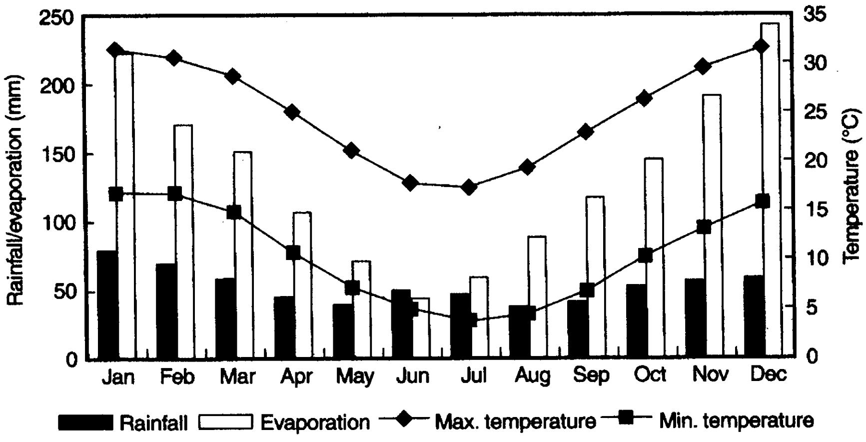

Figure 2.2: Average monthly climatic data for the Upper Hunter Valley (Jerrys Plains). Source: Hannan and Gordon, 1996.

2.3 GEOLOGY, SOILS AND TOPOGRAPHY

The geology of the Hunter Valley is highly variable. However, coal bearing seams are of Permian age, and since the 1980s, coal production has been dominated by open cut mines working two main groups. The lower (Greta) coal measures consist of approximately ten seams that developed from a strong marine influence, and the upper (Singleton-Whittingham) coal measures consist of approximately 20 seams that developed as a continental sequence (McGiddy, 1993). The differences in the environments in which the coal seams were formed resulted in coals with different properties (S. Leary, pers. comm., 2002). On the north eastern side of the Hunter Valley, the Singleton coal measures abut the Hunter-Mooki Thrust, dipping gently towards the southwest boundary where they eventually become overlain by the escarpment-forming Triassic sediments of the Sydney Basin (Hannan and Gordon, 1996).

The upper coal seams are multi purpose in nature, providing low ash soft coking coals, steaming coal of export quality and high ash steaming coal for local-coal fired power stations. Multi-seam mining operations are required as most seams are of variable thickness and liable to splitting over short distances. Open cut mining can only take place where dips are favourable and seams are close enough together to result in economic overburden ratios (McGiddy, 1993).

Soils have developed from the sandstones, siltstones and conglomerates of the coal measures and typically consist of thin, gravelly lithosols on ridges, red and brown podzolics on the upper slopes, and yellow solodic or solonetz profiles on the lower slopes (Hannan and Gordon, 1996). The gravely lithosols lack horizon development and are coarse in texture, while the podzolics are common on sedimentary rocks with strong leaching conditions and the loamy A horizon overlies a red clay B horizon with a strong structure. The solonetz soils have a thin A1 horizon (~10 cm) overlaying a thick, bleached A2, with a sandy loam A horizon and a blocky clay B horizon (Hannan, 1995). The region consists mostly of undulating land giving way to alluvial flats along the Hunter River, with an elevation of approximately 300 m and local relief up to 100 m (Hannan and Gordon, 1996).

2.4 FLORA AND FAUNA

The region's original vegetation consisted of open savannah woodland with ironbark (*Eucalyptus crebra, E. sideroxylon)* and spotted gum *(Corymbia maculata*) on ridges, while forest red gum (*E. tereticornis*), grey box (*E. mollucana*) and rough-barked apple (*Angophora floribunda*) were found along watercourses. Middle and lower slope positions were occupied by bull oak (*Casuarina lehmannii*) with a grass cover of *Themeda, Danthonia, Aristida* and *Astrebla* species. However, much of the original vegetation has been destroyed by pastoral practices and the grass cover is now dominated by the less productive and palatable *Stipa, Aristida* and *Chloris* species (Hannan and Gordon, 1996).

The Hunter Valley provides habitat to a wide array of mammals, avifauna, reptiles and amphibians. For example, mammals such as eastern grey kangaroos (*Macropus giganteus*), foxes (*Vulpes vulpes*) and rabbits (*Oryctolagus cuniculus*) dominate Bengalla mine and 12 other mammal species have been recorded (Envirosciences, 1993). Over 60 species of birds and 12 reptiles and amphibians have been identified in the Bengalla lease and surrounding areas.

2.5 COAL MINING AND REHABILITATION

2.5.1 Legislative Requirements

Since 1973, New South Wales legislation requires that land that has been damaged as a result of mining processes be rehabilitated and returned as closely as possible to its original condition, in terms of productive capacity and topographic appearance (Elliott *et al.,* 1980). In New South Wales, two principal State Acts control the development and operation, environmental management and rehabilitation requirements of coal mines. These are the Mining Act (1992) and the Environmental Planning and Assessment Act (1979). Detailed plans and supporting documentation are required by the Department of Mineral Resources (DMR) in respect to pre- and post-mining landforms, drainage patterns, soil types, stripping and replacement methods, proposals for the final landuse, revegetation and erosion control. The Environmental Planning and Assessment Act (1979) addresses landuse planning activities throughout the State and provides the legislative framework to assess the environmental and social impacts of all major development proposals. This Act requires an Environmental Impact Statement (EIS) to be prepared that involves identifying impacts and rehabilitation techniques for any mining operation (Hannan and Gordon, 1996).

To meet legislative requirements in project development, planning is essential if rehabilitation is to be successful, and it should begin as early as possible (EPA, 1995). This ensures that revegetation is closely integrated with the planning of other mining activities in order to achieve the lowest operating costs and best practice rehabilitation (Bell and Hannan, 1993; Bell, 1996).

2.5.2 Rehabilitation Objective

Pre-mining landuse in the Hunter Valley was dominated by grazing of cattle, sheep and horses on land extensively cleared of native timber (Dragovich and Patterson, 1995; Summerhayes, n.d.). Most of the coal mines in the Hunter Valley aim to rehabilitate their mines so that a post-mining land can sustain low intensity cattle grazing on introduced pasture species (Bell and Hannan, 1993; Dragovich and Patterson, 1995; Figure 2.3). Hence, revegetation is directed towards pasture establishment and selective tree planting on land disturbed by mining activities. Selective tree planting complements pasture establishment and adds windbreaks, wildlife habitat and aesthetic variety across the landscape (Summerhayes, n.d.).

In the upper Hunter Valley, no significant difference was found between the quality of unmined native pasture areas and those pastures growing on rehabilitated coal mines (Dyson *et al.,* 1987). In addition, it was established that rehabilitated sites were capable of supporting and fattening at least as many cattle as the native pasture sites. Similar levels of surface stability, infiltration rates, soil moisture storage and evapo-transpiration rates have also been observed between rehabilitated and native pasture sites in the Hunter Valley (Dyson *et al.*, 1987).

Figure 2.3: Cattle grazing on pastures in the Hunter Valley.

2.5.3 Mining Operations

The typical mining process in the Hunter Valley consists of the land surface being cleared and, prior to mining, the topsoil being selectively stripped at locations and depths that are determined by individual Mining Operations Plans, that are part of the open cut mining approval process (Hannan and Gordon, 1996). The removal of topsoil is dependent on soil quality and type as it contains the majority of seeds, organic matter, labile nutrients and micro-organisms in the soil profile. The extent of topsoil to be stripped is predetermined and is clearly marked with survey pegs prior to removal. The complete A1 horizon is normally removed to 100-300 mm, thereby avoiding other deeper soil horizons containing high clay content and poor structure (EPA, 1995).

Topsoil is either placed in stockpiles for later use in the rehabilitation program or, where possible, is immediately transported to reshaped overburden dumps (see chapter 3). After bulldozers remove the subsoil and weathered rock, the more consolidated rock requires blasting. Drill rigs are used fitted with dust collectors and the time of the blast must be agreed to by the mine operators and surrounding neighbours.

Within the Hunter Valley, two main methods of surface mining are used, namely strip and open-pit mining (Hannan and Gordon, 1996). This creates two methods of overburden removal after blasting. The open-pit method requires a large working space where the removed overburden can be stored in areas until progressive backfilling can take place on one side. At any one time in an open pit, many sites and multiple levels are used to store overburden simultaneously. The open pit method usually uses rear-dump trucks, which enables careful control of overburden dumps. Strip mining, however, uses high capacity earthmoving equipment such as draglines, rope shovels or hydraulic excavators to remove the overburden. This method of mining restricts the dumping range because of the boom length (Figure 2.4). After the first cut has been completed, the machinery advances to the second cut, which enables the backfilling of the overburden from the first cut, thus reducing the land space required to store overburden. After several strips, the spoil piles are reshaped and revegetated according to the rehabilitation program. Coal is usually recovered by front-end loaders or face-shovels loading into rear dump trucks and hauled to a dump station (Hannan and Gordon, 1996).

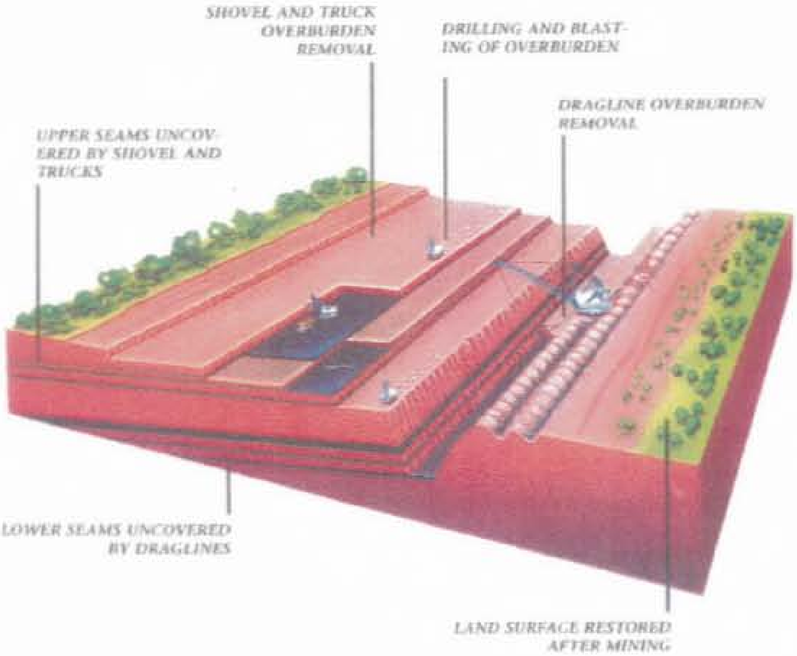

Figure 2.4: Diagrammatic representation of open cut coal mining in the Hunter Valley.
Source: Bengalla Mine.

2.5.4 Rehabilitation Procedures

Rehabilitation procedures in the coal industry in Australia have played an important part in developing pastoral systems and erosion control measures on very steep slopes. At the majority of the coal mines in the Hunter Valley, low intensity cattle grazing on introduced pasture species is the preferred post-mining landuse (Bell and Hannan, 1993). Revegetation has, therefore, largely focused on an ecosystem of pasture species with scattered trees on land disturbed by mining activities. However, some mines have investigated native ecosystems or broad-acre re-afforestation, which could provide landuses for both recreational purposes and as a wildlife refuge (Bell and Hannan, 1993; Marschke, 1996). The rehabilitation procedures outlined below will focus only on the pasture ecosystem landuse.

Landform Reconstruction

The landform reconstruction of a mined site is an essential part of successful rehabilitation (EPA, 1995). Consideration must be given to a range of factors including erosion potential of the reformed surface, slope angle and length, top-dressing materials and vegetation density (Sengupta, 1993). The establishment of pasture poses minimal limitations on re-contoured landscapes, with slopes of up to 10° or flatter being acceptable, provided appropriate contour draining is made to reduce slope length, which promotes pasture strength and, therefore, protects the soil surface (minimising erosion - Bell, 1996). Approval to build slopes up to 18° can be granted in some circumstances (S. Brooks, pers. comm., 2002). Good mine planning and management can minimise the need for extensive re-shaping of spoil piles, however, it is important for the final landform to be hydrologically compatible with the surrounding area (EPA, 1995).

Topsoil Return

After successful spoil dumps have been created and reshaped, topsoil is returned. The use of topsoil material has far fewer limitations to plant growth than overburden material and often rapid establishment of vegetation cover outweighs the additional cost of topsoil handling. In some cases, however, due to the poor chemical and physical quality of some soils within the Hunter Valley, other topdressing materials might be used to establish vegetation, such as subsoil, overburden, interburden and coarse coal washery reject (Elliott and Reynolds, 2000; Bell, 1996). Scrapers are used on the contour (to reduce surface runoff and retain water infiltration) to spread the topsoil material at an average thickness of 100 mm (ranging from 50-300 mm), which is the optimal depth for pasture establishment set by the DIPNR (Hannan and Gordon, 1996). To minimise topsoil erosion, respreading of topsoil is generally carried out as closely as possible to the planned time for pasture sowing (Hannan and Gordon, 1996). Gypsum is added to areas where sodicity is a problem to prevent surface crusting, and in some cases lime is required to reduce soil acidity if pyrite is present in mine spoil (Foster, 1995).

Seedbed Preparation and Tillage

Following topsoil spreading with scrapers, a suitable surface to establish pasture is typically achieved through modification by cultivation. Overburden is rock raked to remove large rocks that would otherwise be disturbed during ripping. Ripping encourages water infiltration, relieves soil compaction, reduces mechanical impedance to plant roots, improves soil aeration, reduces surface crusting and binds the topsoil to the subsoil (Brown *et al.,* 1986; EPA, 1995; Bell, 1996). The typical practice following surface shaping is to rip substrate material to a depth of between 0.5-1.0 m using a dozer-mounted ripper with tynes spaced about 0.9 m apart. The next step involves cultivation with a chisel plough to approximately 0.2 m depth, which produces a coarse, rough seedbed that prevents surface crusting and has deep furrows for moisture retention (Foster, 1995; Hannan and Gordon, 1996).

Fertiliser Requirements

Fertiliser requirements vary widely according to site-specific conditions and the intended post-mining landuse. Different pasture species respond to or tolerate fertiliser inputs differently (EPA, 1995). For example, the recommended application rates for autumn sowing of an exotic pasture mix in the Hunter Valley is 400 kg/ha of a N and P fertiliser (Hannan, 1995; Hannan and Gordon, 1996). However, Huxtable *et al.* (1999) recommends lower fertiliser rates (100 kg/ha of N-P) for autumn sowing of native grasses in this same region.

Returning mined areas to an improved pasture regime requires a starter input of fertiliser and a maintenance program (EPA, 1995). Typically, during the establishment phase at Hunter Valley coal mines, a proportion of the fertiliser (about 50 kg/ha) is retained for mixing with the seed, while the remainder is spread by ground broadcaster or aircraft prior to sowing. In some cases, fertiliser is applied prior to topsoiling or cultivation to ensure incorporation into the plant root zone (Hannan and Gordon, 1996).

Species Selection

Pasture grasses provide rapid erosion control and superior stock carrying capacity compared to adjacent unmined lands (Foster, 1995). The recommended pasture seed mix has been derived from many research field trials across many mines within the Hunter Valley (Hannan and Gordon, 1996). Modifications do occur for both species and rates across different mine sites (Table 2.1). Immediately prior to sowing, legume seed is *Rhizobium* inoculated and then is spread by tractor or truck mounted broadcasters with the remainder seed mix (Hannan and Gordon, 1996).

Table 2.1: Pasture species commonly sown at Hunter Valley coal mines. Source: Modified from Hannan, 1995; Hannan and Gordon, 1996; Huxtable *et al.*, 1999.

Introduced Species	Native Species
Barrel medic (*Medicago truncatula*)	Pitted bluegrass (*Bothriochloa decipiens*)
Couch grass (*Cynodon dactylon*)	Plains grass (*Austrostipa aristiglumis*)
Green panic (*Panicum maximum*)	Queensland bluegrass (*Dichanthium sericeum)*
Lucerne (*Medicago sativa*)	Tall windmill grass (*Chloris ventricosa*)
Phalaris (*Phalaris aquatica*)	Wallaby grass (*Austrodanthonia sp.*)
Rhodes grass (*Chloris gayana*)	Weeping grass (*Microlaena stipoides*)
Subterranean clover (*Trifolium subterraneum*)	Windmill grass (*Chloris truncata*)
Wimmera rye grass (*Lolium rigidum*)	Wiregrass (*Agrostis avenacea*)

Increasing emphasis is being placed on the potential for using native grasses in coal mine revegetation in the Hunter Valley. In 1993, the Hunter Coal Environment Group (HCEG) received funding from the Australian Coal Association Research Program (ACARP) to research open cut coal mine rehabilitation using native pasture species. The project, completed in July 1999, resulted in a set of practical and cost effective management guidelines to incorporate native pastures into current coal mine rehabilitation practices (Huxtable *et al.,* 1999). Native species can lower management inputs in the long-term.

A number of tree species that are commonly sown or planted during rehabilitation of coal mines in the Hunter Valley are listed below (Table 2.2). However, where the dominant landuse will be pasture, the establishment and growth of trees on land can be severely inhibited. This is a result of the competition between the grasses (or weeds) and tree seedlings for moisture, light and nutrients (Hannan and Gordon, 1996). Tree species and grasses should not be sown or planted together. Striping is one method to avoid this. This is achieved by planting or sowing one row or strip of trees into the overburden where competition is reduced, followed by another strip of pasture seeds sown into fresh topsoil.

Table 2.2: Tree species commonly used in rehabilitation programs in the Hunter Valley. Source: Hannan and Gordon, 1996.

Tree Species
Cooba (*Acacia salicina*)
Dwarf sugar-gum (*Eucalyptus cladocalyx*)
Forest red-gum (*E. tereticornis*)
Grey gum (*E. punctata*)
Mugga ironbark (*E. sideroxylon*)
Narrow-leaf ironbark (*E. crebra*)
Orange Wattle (*Acacia saligna*)
She-oak (*Casuarina glauca*)
Slaty box (*E. dawsonii*)
Spotted gum (*E. maculata)*

Sowing Time and Rates

In the Hunter Valley, the more reliable rainfall of late summer and autumn make this period the preferable sowing time (Hannan and Gordon, 1996). The need for a permanent pasture cover and the imbalance between sowing time can be overcome by sowing a mixture of cool and warm season species in early autumn. Initial erosion control can be provided by the cool season plants, which germinate quickly after sowing (predominantly rye grass, clovers and medics). In late spring and summer, these plants have matured and are hayed-off to provide a mulch layer to establish of warm season species (Hannan and Gordon, 1996). Autumn sowing is preferable for both warm and cool season species as the potential for weed competition is reduced at this time of year (Elliott *et al.,* 1980). In the Hunter Valley, seeding rates of introduced pasture species are generally high (up to four times greater than unmined pastures) to offset seedling loss as a result of harsh environmental conditions imposed by overburden material (Table 2.3).

Table 2.3: Typical autumn and spring sowing rates for a variety of pasture species commonly established at Hunter Valley coal mines. Source: Modified from Hannan, 1995; Hannan and Gordon, 1996.

Pasture Species	**Sowing rate (kg/ha)**	
	Autumn	**Spring**
Barrel medic (*Medicago truncatula*)	8-10	-
Couch grass (*Cynodon dactylon*)	4-10	10
Green panic (*Panicum maximum*)	-	8-12
Lucerne (*Medicago sativa*)	4-6	4-6
Phalaris (*Phalaris aquatica*)	6-8	-
Rhodes grass (*Chloris gayana*)	12-18	15
Wimmera rye grass (*Lolium rigidum*)	6-8	-

Management of Rehabilitated Land

Maintenance of rehabilitated areas requires a number of factors to be considered. These include fertilising, erosion control, weed control, pest and vermin control, replanting or re-sowing, grazing management, and fencing to exclude vehicle or stock access (EPA, 1995; Hannan, 1995). At rehabilitated coal mines in the Hunter Valley, the control of the noxious weed *Galenia pubescens* is particularly important. This plant competes successfully against sown species and can greatly reduce the success of a revegetation program (Hannan, 1995). Broad- leafed species, such as *Galenia,* can be controlled with selective herbicides such as Grazon (Huxtable *et al.,* 1999).

To develop newly established pastures, Hannan (1995) and Dyson *et al.* (1987) noted that grazing should not commence for at least two years after sowing, or until grasses have reached approximately 200-300 mm in height. Beyond this time, short, intermittent grazing periods are required to maintain pasture swards (Dyson *et al.,* 1987). Throughout the Hunter Valley, a number of coal mines have carried out research into the effect of grazing on rehabilitated areas, with particular emphasis on determining adequate stocking densities, pasture production and composition, ground cover, soil erosion, and the movement of soluble material in reshaped overburden (e.g. Elliott *et al.,* 1980; Dyson *et al.,* 1987).

CHAPTER 3.
Review of Topsoil Management in Mining Rehabilitation

3.1 INTRODUCTION

This chapter investigates mining rehabilitation processes that are related to topsoil stockpiling, particularly the effect that stockpiling has on the physical, chemical and biological characteristics of the topsoil. A literature search identified a number of possible techniques to use to rehabilitate sites after stockpiling topsoil. The importance of retaining topsoil to achieve the desired post-mining landuse and establish sustainable rehabilitation practices is outlined below. This precedes a review of the literature relating to the effect that increasing stockpile height and other management processes can have on the physical (e.g. soil structure), chemical (e.g. nutrient levels) and biological (e.g. seeds and microbes) properties of soil. The management processes relate to the establishment, storage and rehabilitation phases of topsoil handling. This review focused on Australian research examples on the effects topsoil stockpiling has on soil properties, however, due to limited Australian studies within pasture ecosystems, international literature was also reviewed where appropriate.

Very few studies have investigated the potential deterioration in stockpiled soil and have instead focussed on what happens after the soil is respread. For example, a Canadian review into topsoil stockpiling noted that many studies lacked good controls, and failed to provide a scientific comparison between undisturbed and disturbed soil conditions (Thurber Consultants *et al.*, 1990). Little experimental or monitoring information has been gathered in Australia comparing topsoil properties before and after inclusion in a stockpile. Studies that do compare these two conditions have generally been carried out overseas and, therefore, are only of minor relevance to open cut coal mining in the Hunter Valley. In light of the lack of relevant research into stockpiling, it is important that the degree of degradation of the topsoil is known before stockpiling, during stockpiling and after the soil is respread. This will assist in identifying management options available to ameliorate the topsoil during the respreading operation.

3.2 WHAT IS TOPSOIL?

The surface horizon varies from 0 in rocky substrates to >1 m in alluvial soils and is dependent on soil type and topography. The soil profile consists of an organically enriched surface (A) horizon underlain by a subsoil (B) horizon low in organic matter and interfacing with a zone of weathered rock (C-horizon). The A1 horizon surface soil is generally referred to as the topsoil, which has a high organic matter content, is dark in colour and has maximum biological activity (Charman and Murphy, 2000). It is the most useful part of the soil for revegetation and plant growth and is typically 5-30 cm thick (Charman and Murphy, 2000). The A2 horizon has similar texture to the A1, however it is paler in colour, poorer in structure and less fertile. The A2 is typically 5-70 cm thick, but does not always occur (Charman and Murphy, 2000). Topsoil can be defined in many different ways. For example, biologists define topsoil as the top 2-5 cm, but mining engineers define it as everything down to the first ore layer. Topsoil in this study is defined as the A1 horizon (not including the O horizon), but where it is hard to identify the different horizons the top 300 mm of soil is used.

Overburden consists of unconsolidated material and bedrock removed from above the first mineable coal seam, while interburden is the material between coal seams. Coarse coal reject (known as chitter) from the coal washery plant is made up of particles (rock fragments) of size range 13-125 mm, while fine washery reject ranges from 0.5-13 mm in size (Charnock, 1999).

3.3 ROLE OF TOPSOIL IN MINING REHABILITATION

Most surface soils have far fewer limitations to plant growth than overburden material, and the additional cost of soil handling is generally outweighed by greater success in establishing vegetation cover. However, there are advantages and disadvantages associated with using topsoil that relate directly to the proposed landuse (Table 3.1). For example, when returning a native ecosystem, replacing fresh surface soil to a mined area is the most economical and reliable way to re-establish the wide diversity of species that exist in this ecosystem. However, if the grass (or weed) seed load is excessively high, they may out-compete direct-seeded native shrub and tree species.

Table 3.1: Advantages and disadvantages associated with using topsoil in mine rehabilitation. After Bell, 1996.

Advantages	Disadvantages
Source of species richness	Weed infestation
Beneficial microbes	Erosion hazard
Reduce fertiliser input	Increased area of disturbed land
Cover is established more rapidly	Increased competition
Burial of rock	Cost of handling
Reduces adverse properties of overburden	
More rapid development of nutrient cycling	

Topsoil is often the most important factor in successfully rehabilitating a native ecosystem (EPA, 1995). A study in rehabilitated bauxite mines in Western Australia found that 137 plant species (72% of the native plant species recorded) in recently rehabilitated areas originated from the fresh soil seed bank rather than from applied seed. This indicates the importance of topsoil conservation in promoting species richness in recently rehabilitated areas (Koch and Ward, 1994). Although topsoil is very important in terms of species richness, other establishment mechanisms, such as sowing seed, can be more important in terms of plant density and cover.

The use of topsoil promotes high growth rates and levels of plant production, species diversity, microflora populations, sustained high levels of both infiltration and porosity, low levels of bulk density in the plant root zone, and a balanced pool of nutrients in association with a high level of stored soil organic matter (Elliott and Reynolds, 2000). Only at a great cost can the diversity of naturally occurring A1 horizon soil material be duplicated (Elliott and Reynolds, 2000). Therefore, to preserve this diversity with selective topsoil placement, amelioration of materials may be required (Bell, 1996). Where possible, topsoil should be lifted, transported and spread on a re-contoured area in one operation (known as direct return).

Topsoil in the Hunter Valley is normally used for pasture re-establishment in rehabilitated areas or where the use of an alternative substrate such as overburden or spoil cannot alone support the desired post-mining landuse (Bell, 1986). Soils covering a particular mining area may be diverse and not necessarily of suitable quality. This is generally the case within the Hunter Valley coal mine operations, with the majority of topsoil being shallow and of poor chemical and physical quality (Huxtable *et al.,* 1999). Topsoil is a scarce resource in the Hunter Valley with soil types varying across mine sites. If not monitored and managed correctly, chemical, physical and biological parameters of the soil can be diminished from the pre- to the post-mining stages. It is imperative, therefore, that site soil maps are prepared and soil samples analysed before rehabilitation (Hannan, 1995).

Grant (unpub.) developed a process diagram that outlines important considerations relating to topsoil management of the different stages of the mining and rehabilitation process in the Hunter Valley (Figure 3.1). The following sections review topsoil management according to this process.

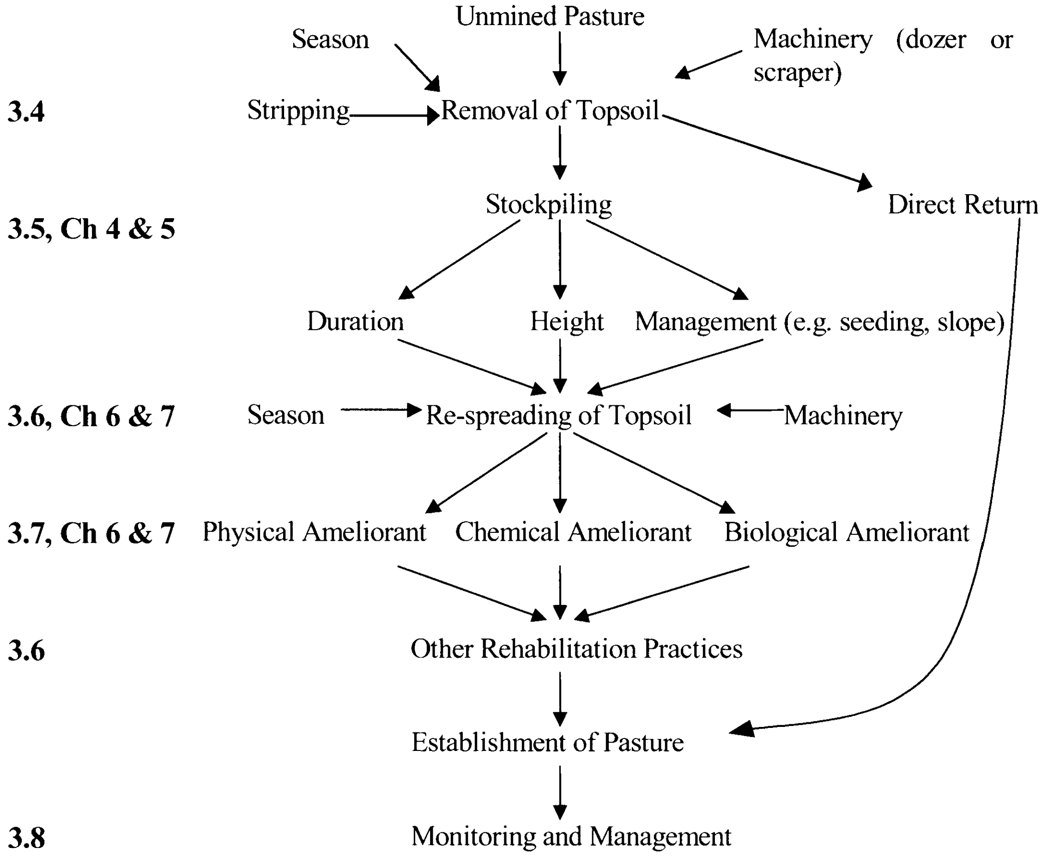

Figure 3.1: Diagram outlining the process of topsoil management in the Hunter Valley (Grant, unpub.). Bolded text on the left refers to aspects of stockpiling processes examined in relevant chapters and sections of this thesis.

3.4 REMOVAL OF TOPSOIL

3.4.1 Depth

The depth that topsoil is stripped at mine sites in Australia varies greatly, and relates to the quality and quantity of topsoil. Due to soils varying in both lateral and vertical properties, the depth of suitable soil that may be stripped for use in a rehabilitation program should be based on detailed chemical and physical analysis for stripping and be recorded on a map (Bell, 1996). Many options exist for stripping, however, the preferred option depends on the quality of the soil available (Bell, 1996):

- Single stripping is appropriate where the entire soil profile may be removed together if all horizons are satisfactory for plant growth.
- Double stripping should be used where each horizon may be removed separately, thereby allowing replacement in the order that the topsoils were stripped or allowing the separate topsoils to be mixed. Stripping the nutrient and microbial rich A horizon separately from the subsoil horizon provides the opportunity to recreate the soil profile. A mixing of the horizons dilutes the native plant propagules and the full beneficial effects of surface organic matter and micro-organisms.

- Combined stripping techniques involve removing a thin layer of the soil surface prior to stripping as most native seeds are concentrated in the top 20 mm of soil. This can be achieved by using industrial vacuum machines or bobcats. The remaining soil can then be single stripped.

Mining companies should aim to keep the different soil layers separate as much as possible, relying on local knowledge of soil types and reducing the mixing of the topsoil with deeper layers. Double stripping involves removal of the topsoil separately from the underlying overburden (or B horizon). Mixing can affect nutrient concentrations, seed stores and texture of the soil, however it is often too costly to remove topsoil layers separately. Double stripping is most important when attempting to return a native ecosystem. Topsoil should be stripped as thinly as possible when returning a native ecosystem. This is because the majority of the seed store, nutrients and organic matter are contained in the upper few centimetres of soil. For example, Grant *et al.* (1996) found that the emergence of 12 species used in bauxite mining rehabilitation in Western Australia was significantly reduced at depths greater than 5 cm and recommended that topsoil be stripped and spread as thinly as possible to maximise establishment.

Tacey and Glossop (1980) evaluated the effects of soil handling operations on seedling numbers, diversity and cover in a bauxite mining rehabilitation study in Western Australia. Double-stripping and direct return of the top 5 cm of topsoil over a stockpiled soil layer led to an increase in groundcover compared with direct return of the whole mixed profile or return of stockpiled topsoil. They also demonstrated that in four year old rehabilitated pits where the double stripping technique was used, the resultant plant community was approaching those of the unmined forest in terms of species richness, diversity, plant and litter cover. Nichols and Michaelson (1986) monitoring the same trial found that, seven years after rehabilitation, the vegetation community on a site that received double stripped soil was more similar to a forest control than sites that received single stripped soil (whole return).

3.4.2 Timing

For rehabilitation to be successful, the timing of topsoil stripping can be important. When considering soil removal and placement, two important factors are the equipment used and the moisture content of the soil. Both factors influence the degree of soil compaction and structural breakdown that occur during these procedures. Where possible, soils are handled by equipment when sufficient moisture is present to help minimise compaction and ensure that plant growth will not be inhibited. The soils, however, still need to be dry enough to inhibit the spread of plant diseases. Bulk density is an indirect measure of aeration and mechanical impedance that inhibits plant growth (Bell, 1996). For example, a loaded scraper can increase the bulk density of many moist soils above a critical limit for root growth (Bell, 1996). The bulk densities above which plant growth may be impeded are about 1.3 g/cm^3, this varies for different soil types where clay soil are 1.25 g/cm^3 to 1.75 g/cm^3 for sandy soils (Mc Queen and Ross, 1982; Bell, 1996; Singer and Munns, 1996). In an ideal situation, soils should be stripped and replaced at a moisture content of between 10 to 15% to avoid the adverse effects of compaction and structural breakdown (Bell, 1996).

Topsoil to be stripped should be moistened, not saturated, whenever practicable to prevent dust generation (EPA, 1995). Furthermore, topsoil deteriorates the least when the soil is stripped in a moist condition (Elliott and Veness, 1985). Any saturated topsoil should not be stripped, as this may result in compaction, loss of structure, death of soil organisms, and lead to germination of seeds and possible death of plants because of a lack of follow-up rain. Local knowledge of the different soil types is essential when determining the ideal soil moisture condition to strip the soil without damage (EPA, 1995; Bell, 1996).

If the objective of rehabilitation is to establish a native ecosystem and to maximise seed stores in the soil, it is advisable to clear and strip soil after native species flower and seed set (EPA, 1995; Ward *et al.,* 1996a). For example, Ward *et al.* (1996a) investigated seed stores in jarrah forests in Western Australia across different seasons. The maximum number of seeds occurred in the soil in summer following flowering in spring, while the minimum number of seeds occurred in winter after germination following winter rains. As a result, summer is the best time to strip and spread topsoil. If, however, the objective is to maximise the contribution of other plant propagules in a pasture ecosystem (e.g. lignotubers, rhizomes and roots), then the optimum time to strip soil may be when soils are cool and wet. However, there is a risk of spreading plant pathogens and affecting soil structure when stripping with wet soil (EPA, 1995).

Like physical soil properties, biological properties are affected by the timing of stripping and the moisture content of the soil. Soils too wet or too dry when stripped can lead to a loss of viable seeds and a reduction in the ability of vesicular arbuscular mycorrhizal (VAM) fungi to associate with plants (Miller *et al.,* 1985; EPA, 1995; Ward *et al.,* 1996a). Stripping of topsoil directly decreases the infectivity of VAM fungi in the soil. Vesicular arbuscular mycorrhizae, however, are most tolerant of disturbance during the dry season where propagule numbers are at a maximum, and propagules are in a form that are best able to survive disturbance and the absence of host plants (EPA, 1995).

3.4.3 Machinery

The types of equipment that are commonly used to remove topsoil include excavators, backhoes, loaders, graders, bulldozers or scrapers (Figure 3.2). The nature of the equipment is important because it influences the degree of compaction and structural breakdown that may occur during soil removal and placement (Bell, 1996). Some compaction from heavy wheeled vehicles during stripping is unavoidable (Bradshaw and Chadwick, 1980). However, excessive compaction of mine soils can slow organic C and N accumulation and inhibit the recovery of microbial activity (Stroo and Jencks, 1982; Harris and Birch, 1989). Scrapers are versatile machines to selectively remove and place soil horizons. However, they can cause significant compaction and have limited economical haulage distances (up to 1 km - Bell, 1996). Scrapers are most efficient when moving large amounts of soil material short distances. The use of a bulldozer or grader for spreading soil piles dumped by trucks, however, is an alternative to reduce sub-surface compaction. A combination of a front-end loader, truck and bulldozer to remove, transport and spread topsoil is by far the best machinery to reduce compaction and inhibit other factors related to plant growth establishment (Bell, 1996). Accurate control of stripping depth is difficult with large scrapers in bauxite mines in the Darling Range of Western Australia (Grant *et al.*, 2004). Graders were originally used instead of scrapers to strip the surface topsoil at a depth of 5 cm in Bauxite mining rehabilitation in Western Australia (Tacey and Glossop, 1980). McQueen and Ross (1982) investigated physical characteristics in the construction of stockpiled topsoils in New Zealand. The study identified that bulk density, total porosity, macro porosity, available moisture and penetration resistance all deteriorate as a result of compaction from the mechanical operation of earth-moving equipment.

Figure 3.2: Machinery used for the construction of stockpiles (a) loader and truck, (b) bulldozer and (c) scrapers.

Grading or pushing soil into windrows with graders or bulldozers for later collection by scrapers or for loading into rear dump trucks by front-end loaders are examples of lower impact soil handling systems (Elliott and Reynolds, 2000). These soil handling systems reduce the compaction effects of heavy equipment, which is often necessary for economical transport of material. It is more beneficial to undertake a single operation of stripping and transporting the topsoil to the rehabilitated area. However, this may not be possible because of the timing of operations or disease issues (e.g. jarrah dieback) and topsoil may need to be stored for a period of time. Jarrah dieback refers to the death of many native species as a result of the spread of the root pathogen *Phytophthora cinnamomi* (White *et al.*, 1996). Hence, topsoil storage may increase transportation costs and structural degradation of the topsoil, which inhibits the viability of much of the seed contained in the soil, and reduces revegetation success and species diversity of the rehabilitated land (Hannan and Gordon, 1996).

Research into rehabilitated bauxite mines at Weipa in northern Queensland (Australia) identified changes to the physical, chemical and microbiological parameters of the soil resulting from alternative topsoil handling operations that focussed on organic carbon (Schwenke *et al.*, 2000a). The effects of soil stripping and replacement were investigated through an experiment comparing four methods; dual stripping (mixing of A and B horizons), double stripping, stockpiled soil and subsoil only. The authors indicated that dual stripping should be discouraged in the native forest area at Weipa as this method caused a decline in organic matter from the surface, and the mixing with gravely soils permanently lowered the soils productive potential that cannot be ameliorated in the short term. Rehabilitation management that immediately replaces stripped soil and conserves the topsoil 'A' horizon is more likely to result in better nutrient storage (organic matter) and availability and should therefore promote long-term stability (Schwenke *et al.*, 2000a). Short *et al.* (2000) conducted a field trial to evaluate the effect of soil handling during bauxite mining at Weipa on the distribution of P in Brown Kandosol soils that are extremely P deficient. They found that stripping and replacing soil disrupted the P cycle and affected the proportional distribution of available P. During soil handling, horizon mixing reduced the size of plant available soil P fractions (from 100 µg/g in undisturbed soils to as low as 35 µg/g) in surface soils (0-5 cm depth). Compensation for this loss can, therefore, only be rectified with the addition of fertiliser.

3.5 STORAGE OF TOPSOIL

3.5.1 Introduction

Many factors influence the storage of topsoil for any given operation. These include the type of disturbance, quantity of material to be salvaged, equipment available for stripping and storage operations, long-term planning, available space, storage time and the economics of various storage alternatives (Thurber Consultants *et al.*, 1990). Direct return is the preferred management option, however, in the Hunter Valley, like many mines throughout Australia, direct return is not always feasible. Throughout the process of mining, topsoil may have to be stored in stockpiles until mine spoil is ready for revegetation.

Topsoil can deteriorate in many ways during storage. Topsoil buried deep in a storage pile may become anaerobic and if this occurs, its physical structure, chemical and biological components will undergo changes, which inevitably can affect its quality in terms of rehabilitation. Some examples of deterioration resulting from stockpiling include soil structural decline, organic matter and nutrient loss, death of seed and plant propagules, and reduction in populations of beneficial soil micro-organisms (EPA, 1995; Hannan, 1995).

The productive capability of land can be examined prior to mining to reveal the attributes and limitations of most sites. The management of land prior to topsoil stockpiling can have an effect on the soil qualities before stockpiling even occurs. The management of weeds, grazing pressure and seed set prior to the soil being stripped can affect the compaction, grass and weed seed content of topsoil (S. Brooks, pers. comm., 2002). For example, weed infestation may result from inadequate ground-cover of native species that would normally compete and keep weeds under control (Hannan, 1995).

3.5.2 Height

In the Hunter Valley, limited land space affects the height and surface area for stockpiles. As a result, stockpiles have tended to be constructed to greater heights. The Department of Infrastructure, Planning and Natural Resources (DIPNR) suggests that the optimum height of stockpiled topsoil in the Hunter Valley is no more than 60 cm. This depth is appropriate to regenerate and preserve soil attributes that influence plant growth and is based on Elliott and Veness (1985). Stockpiles should never exceed 3 m (DIPNR guidelines; Elliott and Veness, 1985, Charman and Murphy, 2000). Although this guideline has been created to manage stockpiles in the Hunter Valley, there is little scientific basis to support this guideline.

Research has been carried out on stockpile height effects on soil properties (Elliott and Veness 1985), seed stores in topsoil (Iverson and Wali, 1982; Bellairs and Bell, 1993; Ward *et al.*, 1996a), microbial activity (Visser *et al.*, 1984a; Harris *et al.*, 1989; Johnson *et al.*, 1991), and mycorrhizal fungi (Miller and Cameron 1976; Rives *et al.*, 1980; Visser *et al.*, 1984b). Chemical processes can be affected by the height of topsoil stockpiles, particularly the processes that occur under aerobic and anaerobic conditions. In stockpiled topsoil, studies have identified an accumulation of mineral N, in particular NH_4-N (O'Flanagan *et al.*, 1963; Ross and Cairns, 1981; Abdul-Kareem and McRae, 1984; Visser *et al.*, 1984a; Harris and Birch, 1988). For example, Harris and Birch (1988) found high levels of NH_4-N at lower depths (100 to 125 cm) in a topsoil stockpile in the UK, remaining constant to the bottom of the stockpile. Nitrate-N levels peaked at about 100 cm before declining, but above the depth where NH_4-N decreased. They attributed this change to leaching of NO_3-N from the upper layers of the stockpile. This was subsequently converted to NH_4-N in the anaerobic areas of the pile during storage. However, an alternative explanation is that oxygen supply was so low with depth that nitrification was inhibited, however denitrification was able to occur (NO_3-N is reduced to nitrous oxide - N_2O

and dinitrogen - N_2 gases), while NH_4-N was slowly released by the mineralisation of organic N as organic matter decomposed. In addition, Harris and Birch (1988) noted increased organic carbon contents and an increase in total N levels between 100 to 125 cm depths. In contrast, Bradshaw and Chadwick (1980) stated that total N becomes depleted during storage through the denitrification process and leaching.

Mineral nitrogen (NH_4-N) accumulated up to 400 mg/kg at depths greater than 1.8 m in stored stockpiles in New Zealand and was attributed to the low oxygen supply that resulted in very low levels of nitrification at depth in the piles (Ross and Cairns, 1981). O'Flanagan *et al.* (1963) investigated the upper levels (60-90 cm) of two stored sandy loam topsoil stockpiles for a period of three years in Lancashire, U.K. They reported an accumulation of NH_4-N and concluded that a slower rate of nitrification in a stockpile could be attributed to the increase in anoxic conditions and a reduction in nitrifying bacteria activity. A topsoil stockpiling study in New Zealand found ryegrass had higher yields in the lower part of the stockpile compared with those at the top, due to high in levels of mineral N accumulating under anaerobic conditions towards the middle of the stockpile (Widdowson *et al.*, 1982).

Investigation of the effect of stockpiling soil on micro-organism populations has identified decreasing numbers as depth in the stockpile increased (Harris *et al.*, 1989). Johnson *et al.* (1991) studied the effect of anaerobic conditions with depth within stockpiles in the Midlands (UK) and found a decrease of aerobes with increasing depth. The number of bacteria, fungi, actinomycetes and algae were reduced in stockpiled soil when compared to undisturbed sites (Miller and Cameron, 1976). Stark and Rendente (1987) also established a relationship between topsoil stockpiling and a decrease in microbial activity and mycorrhizal infection potential.

In the Bowen Basin (Australia), Anderson *et al.* (1988) investigated the carbon dioxide (CO_2) content of the soil during stockpiling and reported that CO_2 increased with depth in the stockpile, but to a greater extent in wet than dry soil. Williamson and Johnson (1990a) investigated microbial biomass carbon in stored and respread soils at opencast coal sites in the United Kingdom. Significant amounts of microbial biomass were found in stockpiled soils, however the vast majority were dead. During stockpiling, bacteria had low percentage cell viability and were non-viable, once respread, however, these measures increased. In addition, within the stockpile, higher levels of carbon were found at lower depths, with a large number of bacterial spores accounting for the biomass (Williamson and Johnson, 1990b). Visser *et al.* (1984a), in a study on the effect of storage on microbial activity in Alberta (Canada), also found lower levels of microbial biomass carbon in stockpiled soils than in undisturbed soils.

Stockpiling can have undesirable effects on biological soil properties. Jasper *et al.* (1987) states that stockpiling of soil results in substantial loss of propagules stored deeper than 1 metre. The loss of propagules will be greatest in tall stockpiles stored for a long time. Rhizobia can also be severely affected by stockpiling. The rate of recovery of VAM fungi in respread stockpiled soil may depend on the level of mixing with surface soil that occurs during spreading (Jasper *et al.*, 1987). Decreases in microbial activity and mycorrhizal infection potential can occur in stockpiled soils and this can depend on vegetation in the stockpiled soil and depth of burial. Stark and Rendente (1987) state that the biological effects that occur due to stockpiling leads to reduced nutrient cycling and lower availability of nutrients, which can produce unfavourable conditions for revegetation through lower plant establishment and productivity.

3.5.3 Stockpile Design

Storing topsoil in broad and shallow stockpiles is the preferred method, with subsequent conditions most suitable for maintenance of soil and vegetative characteristics (Visser *et al.*, 1984b; Elliott and Veness, 1985; Hannan 1995; Bell, 1996; Ward *et al.,* 1996a). Soil deterioration can be influenced by the shape and size of topsoil stockpiles. Harris *et al.* (1989) developed a tentative model to provide a focus for future research (Figure 3.3). This identified three zones of importance in a stockpile: a zone that is predominantly aerobic throughout the life of the stockpile, a transition zone that fluctuates between aerobic and anaerobic states, and a zone that is predominantly anaerobic.

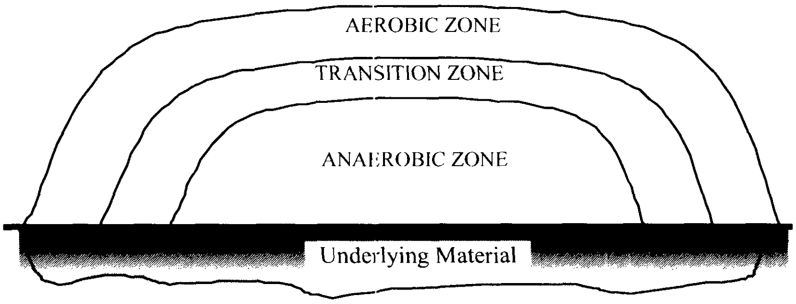

Figure 3.3: Schematic cross-section diagram indicating three zones in a topsoil stockpile (Harris *et al.*, 1989).

Very few studies of stockpile designs and management have been undertaken that specifically investigate seed banks. Of the studies carried out, only a small number have looked at the viability of seed banks within artificially created stockpiles, and these have focused on bauxite and sand mining operations where a strip mine method is used (Koch *et al.*, 1996; Ward *et al.*, 1996a; Grant and Koch, 1997; Ward *et al.*, 1997). Elliott and Veness (1985) focussed on designing and managing topsoil stockpiles with reference to the dimensions. In light of these studies, broad and shallow stockpiles provide the best conditions for seed banks, vegetative material and aerobic organisms to survive. Hannan (1995) suggests a minimum height and maximum surface area to reduce vegetative decomposition caused by the formation of anaerobic conditions. Abdul-Kareem and McRae (1984) studied 18 constructed topsoil stockpiles representing a range of textures (sand, loam and clay), ages (1.5-7 years) and heights (3-7 m).

The most obvious change in stockpiled soil was the visible change (darkening of the soil) and presence of a characteristic anaerobic 'smell' that identified the anaerobic layers within 0.3 m of the stockpile surface for clayey textured soils, but a 2 m depth for sandy textures No major parameters were affected by stockpile height and the authors suggested that the extent of deterioration of soil in stockpiles may have previously been overestimated.

A study in India compared six different age classes (1, 3, 4, 6, 9 and 10 years) of topsoil stockpiles by sampling to a depth of 0.2 m to unmined areas (Ghose, 2001). Levels of biological activity declined every year leading to stockpiles becoming biologically sterile when compared to unmined topsoil. To maintain soil quality, stockpiles should be constructed to improve the reduction rates of soil microbes by providing a maximum surface area and consisting of slopes capable of avoiding erosion and gully formation. However, the overall size and shape of stockpiles are usually dictated by space constraints at mine sites and topsoil texture. Ghose (2001) suggests that stockpiles are constructed to a maximum height of 5 m. If the topsoil consists of a heavier soil, then the stockpile should be as shallow as possible, ideally less than 1 m in height. Particle size analysis revealed that sand particles increased, while silt and clay particles decreased in stockpiled topsoil when compared to unmined soils, and the author attributed this to the increased erosion (Ghose, 2001). This study identified that greater levels of sand particles indicated lower aggregate stability and a higher rate of infiltration. Ghose (2001) also suggested different stockpile heights for different soil textures namely :

- 5 m (max.) for sandy soil;
- 2-3 m for loamy soil;
- 1 m for heavy clayey soil;
- 0.5-1 m (max.) for intermediate soil texture.

3.5.4 Time

Weather conditions and mining activities can create difficulties when determining the best time to rehabilitate a site. Some topsoil may have to be stockpiled for later use. Stockpiles can be stored for days, months, years or even decades, depending on the requirements of the mining operations (Stark and Rendente, 1987; Johnson *et al.,* 1991). The question is not whether degradation is occurring when soil is stockpiled, but to what extent, and how can the degradation process be slowed or minimised. For example, Bell and Hannan (1993) state stockpiling for periods longer than 6 months may cause structural degradation and deaths of seeds and micro-organisms. Visser *et al.* (1984a) stated that stripping and storing of topsoil reduced organic carbon at the surface of a stockpile greater than three years old. The change in chemical properties of the topsoil resulted from mixing rich topsoil with the underlying mineral soils. Furthermore, these authors reported that topsoil stockpiled for 15 days led to a decrease in microbial activity in surface layers, with higher levels found in the bottom layers. However, these levels were still lower than in undisturbed soils. In addition, Harris *et al.* (1989) found a substantial decrease in microbial biomass and numbers in stockpiled topsoils, with numbers of aerobic bacteria decreasing with prolonged storage of the topsoil, as indicated by the N pool and a decrease in measured organic carbon content. Soil quality exhibited a continuous annual decrease that led to the soil becoming barren in biological components (Ghose, 2001)

Stockpiling topsoil for short time periods (1-6 months) can substantially decrease seedling recruitment and species richness when compared to directly returned topsoil (Tacey and Glossop, 1980; Koch and Ward, 1994; Ward *et al.*, 1996b). For example, the viability of buried *Andersonia involucrata* seed at Alcoa's Jarrahdale mine declined from 98% to <2% within one month (Dixon and Nielsson, 1992). This may be attributed to the decomposition of seed triggered by elevated moisture and temperature conditions within the stockpile. Anderson *et al.* (1988) compared the soil properties of two Bowen Basin soil types (black earth and brown gradational) in both wet and dry conditions to assess the effects of stockpile storage time. Rapid increases in NH_4-N were noted following stockpiling on both soils. Concentrations peaked after 5 months under wet conditions and 15 months on the dry piles. Over the 40 month study period, the concentrations of NH_4-N gradually declined (Anderson *et al.*, 1988).

3.5.5 Vegetation Cover

Stockpiles should be revegetated to protect the soil from erosion, discourage weeds and maintain active populations of beneficial soil microbes. In addition, establishing plant cover on stockpiles decreases the exposure of the soil surface to raindrop impact, decreases the likelihood of aggregate breakdown, and hence surface sealing and crusting, run-off and erosion, and increases infiltration rates and water storage (Thurber Consultants *et al.*, 1990). For example, to optimise development of organic matter in the soil after mining, Schwenke *et al.* (2000b) suggests that grasses be added when stockpiling soil to ensure organic inputs are maintained in the stockpile and soil compaction and gravel incorporation are minimised. These factors can cause permanent limitations to plant growth. Ghose (2001) suggests that if storage is unavoidable the stockpiles should be thoroughly ripped with suitable subsoiling machinery to diminish surface compaction caused by the passage of scrapers, the soil be aerated, and deep rooting vegetation be introduced. Furthermore, low maintenance species should be sown immediately following ripping to prevent erosion and gully formation, with surface vegetation being actively maintained with seeding and weed control procedures (Ghose, 2001).

3.6 REHABILITATION FOLLOWING TOPSOIL STOCKPILING

3.6.1 Introduction

Topsoil respreading should be based on revegetation programs that were established in the planning phase of the mining operation. Revegetation programs should be based on a sound knowledge of inhibiting factors that could affect the establishment of a stable and persistent ecosystem on mined land (Bell and Hannan, 1993). This typically involves systematic investigation of the:

- Local climate and landscape conditions;
- Spatial variation of the material to be used;
- Capacity of potential growth media to support plant growth;
- Requirements for selective handling or placement of the material (e.g. topsoil); and
- Plant species likely to establish and persist.

A range of possible rehabilitation strategies can be used to overcome or ameliorate site factors (Bell and Hannan, 1993; Bell, 1996; Elliott and Reynolds, 2000). This section describes the benefits of using direct return topsoil in place of stockpiled topsoil in rehabilitation areas, identifies important factors during respreading of topsoil and briefly discusses other important rehabilitation practices (see Figure 3.1). The following section (3.7) identifies the physical, chemical and biological limitations to successful rehabilitation following topsoil stockpiling and outlines techniques for amelioration.

3.6.2 Stockpiling Compared to Direct Return

Direct return of topsoil is preferable to stockpiling, where topsoil should be lifted, transported and spread on a reshaped area in one operation (EPA, 1995; Hannan, 1995). Compared to stockpiling of topsoil, direct returned soil maintains live micro fauna and flora (Hannan, 1995). In addition, direct return avoids double handling, minimises extra cleared land for stockpile creation and can maintain greater soil qualities than stockpiling (EPA, 1995). Although topsoil is handled in both processes, stockpiling of topsoil leads to anoxic zones, structure decline, losses of organic matter and nutrients, deterioration of seeds and beneficial micro-organisms are reduced (EPA, 1995). Fresh topsoil can contribute greater species diversity than stockpiled soil. For example, an investigation into the abundance and richness of the topsoil seed store prior to mining and during rehabilitation procedures following bauxite mining in Western Australia, found that the majority of seeds stored in the soil could be lost during this process (Figure 3.4 - Koch *et al.,* 1996). However, it was identified that fewer seeds were lost when topsoil was directly returned to rehabilitated sites rather than being stockpiled.

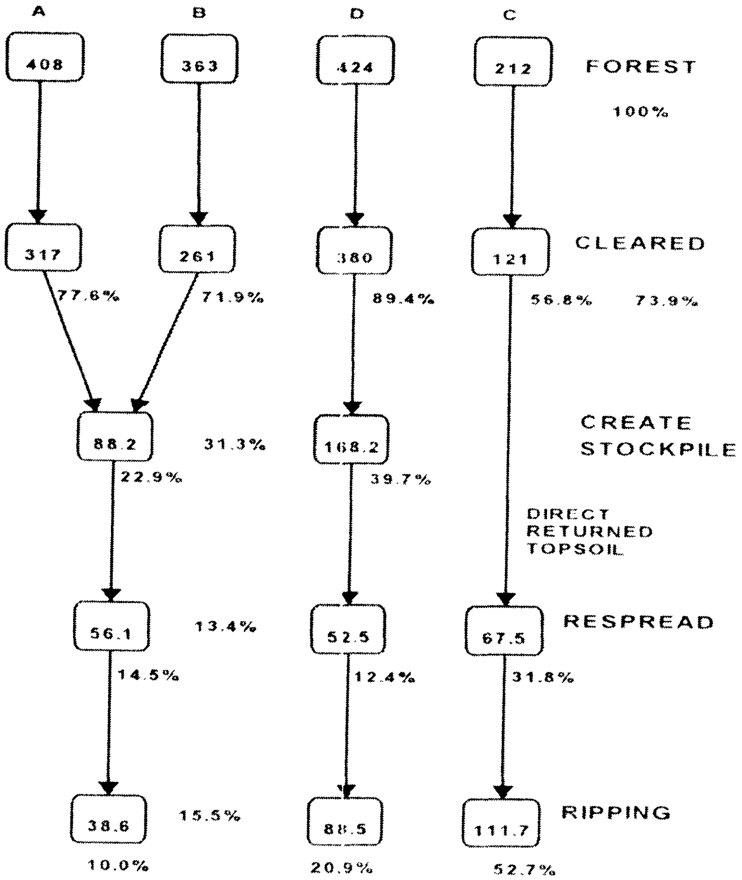

Figure 3.4: Seed density (m^{-2}) for the four forest sites during bauxite mining and rehabilitation procedures. Percentages are based on the original forest seed densities. Soil from site C was directly returned. Soil from the other sites was stockpiled for 10 months, with the soil from sites A and B being combined into one stockpile (after Koch *et al.*, 1996).

3.6.3 Respreading of Topsoil

The nature of soil handling and, in particular, the type and size of equipment used, limits the accuracy with which the soil profile can be respread and reconstructed on rehabilitated areas. Due to this accuracy problem, rehabilitation areas can display more than four outcomes, e.g separate storage and stockpiling of A and B horizons. The first is where the A horizon portions that have been correctly replaced over the B horizon; second is the 'mixing' of both A and B horizons; thirdly is where the B horizon material is placed at the surface; and fourthly is where soil has been stockpiled for an extended period, the storage process mixing the A and B horizons, and causing a reduction in soil fertility prior to respreading (Short *et al.*, 2000).

Scrapers are the most commonly used machines for spreading topsoil (Hannan and Gordon, 1996). Scrapers are used on the contour with minimal movements to avoid creating tracks, which could create gully erosion after heavy rain or result in over-compaction of previously topdressed surface soil (Hannan and Gordon, 1996). Bulldozers can also spread topsoil after it has been transported to the reshaped area by rear-dump trucks (Hannan and Gordon, 1996).

To maximise species richness from stockpiled topsoil for rehabilitated areas, Bradshaw and Chadwick (1980) suggest that topsoil layers, when respread, should be at least 10-20 cm thick.

This is usually determined by the quality and quantity of the underlying material (Bell, 1996). An investigation by the Department of Infrastructure, Planning and Natural Resources has indicated that the optimum depth for respreading topsoil to establish pasture should be 10 cm (Hannan and Gordon, 1996). Hannan (1995) indicated that field studies carried out in the Hunter Valley show that to establish pasture a topsoil thickness of 5 cm is adequate (where the underlying material does not have major limitations). No significant increase in pasture growth was evident with a greater thickness of topsoil spreading (Bradshaw and Chadwick, 1980). However, the limitations of large machinery may mean that a smooth reshaped surface of spread topsoil cannot be achieved to a 5 cm depth. Koch *et al.* (1996) and Grant *et al.* (1996) found that the depth of returned topsoil is important for optimal utilisation of the seed store. These studies focussed on the jarrah forest ecosystem in Western Australia. However, the studies indicated that burying seeds at a depth greater than 5 cm significantly, or in some cases completely, reduced seedling emergence. The more advanced techniques that have been successfully practiced across Australia within native ecosystems can be adapted and tailored to pasture ecosystems to maximise the return of plants from the seed stores of topsoil.

When stockpiled topsoil is used to revegetate an area, different methods can be used to enhance rehabilitation success. For example, using species with a lower dependency on symbiotic relationships with micro-organisms may be beneficial, while many grasses establish well in stockpiled soils (Stark and Rendente, 1987). However, this depends on the rehabilitation objective. Legume species inoculated with compatible *Rhizobium* bacteria immediately prior to sowing allows the companion grasses and the legume species to supply nitrogen, which is important for long-term pasture stability (Bell, 1996). Having a good soil structure also retains water, which avoids the need to consolidate the topsoil. This can be achieved by ripping the topsoil, which may improve the underlying soils permeability (Bradshaw and Chadwick, 1980).

3.6.4 Other Rehabilitation Practices

Deep ripping and timing of return are other important rehabilitation practices that need to be considered. Rehabilitation areas can be deep ripped (0.5 to 1.5 m) on the contour by tynes attached to a dozer or grader to reduce soil compaction resulting from the heavy machinery traffic involved in the mining, dumping and reshaping operations, regardless of whether the soil is replaced or not. Ripping reduces the mechanical impedance to plant roots, and improves soil aeration and water infiltration (Bell 1996). Poor water infiltration and mechanical impedance to root growth and seedling emergence resulting from crust formation can be overcome by deep ripping and cultivation (Johnston, 2000). The ripping technique can have an effect on topsoil burial (Grant *et al.,* 1996). During the rehabilitation process, ripping topsoil can cause excessive burial of the soil seed bank. However, a significant increase in seedling recruitment after topsoil was ripped has been recorded, which probably resulted from scarification of hard-seeded species (Koch *et al.*, 1996). After ripping overburden, rehabilitated areas that are to be grazed by domestic stock should be rock raked to remove all rocks greater than 200 mm in diameter (Figure 3.5).

Figure 3.5: Machinery used for rock raking after ripping of overburden.

The timing of soil return to a rehabilitated site is also important. Ward *et al.* (1996b) investigated the effects of different ripping, seeding and scarifying dates on plant establishment from applied seed and from propagules stored in the topsoil in areas being rehabilitated after bauxite mining in Western Australia. The authors found that rehabilitated bauxite pits that were ripped in December or February exhibited a significant increase in plant establishment from the topsoil compared to sites that were ripped in April. The study concluded that the ideal revegetation sequence needed to maximise seed store contributions in establishing native plants is to collect the topsoil immediately after clearing the vegetation in summer, immediately return the soil to an area to be rehabilitated, and carry out all earthmoving, landscaping and seedbed preparations prior to the onset of the autumn rains.

3.7 LIMITATIONS TO VEGETATION ESTABLISHMENT

3.7.1 Physical Limitations and Rehabilitation Options

Topsoil quality can be affected by compaction or mechanically handling the soil using heavy earth moving equipment. The physical characteristics of soil that affect plant growth and function caused by topsoil removal, storage and replacement include bulk density, particle size distribution, aggregate size and stability, soil structure (aggregation of primary soil particles), water holding capacity, hydraulic conductivity and soil strength (Thurber Consultants *et al.*, 1990; Bell, 1996). An increase in clay and silt percentages through the soil profile potentially indicates restrictions to root growth and water movement (McKenzie *et al.*, 1999). Particles of 0.05-0.5 mm are prone to movement by wind, and they can result in abrasion and seedling coverage (Bell, 1996). Bulk density is an indirect measure of aeration and mechanical impedance, which directly affects plant growth (Bell, 1996). A soil profile's permeability is usually determined by hydraulic conductivity. If hydraulic conductivity is low, this will cause waterlogging and, depending on the landscape setting, can generate runoff and erosion (McKenzie *et al.*, 1999).

The addition of calcium salts (gypsum) at a rate of approximately 5-10 t/ha can reduce surface crusting, improve structure and texture, and increase water infiltration, aeration and seedling emergence (Johnston, 2000). As an erosion control measure, contour ripping can help reduce an areas susceptibility to erosion. Where wind erosion is a problem, windbreaks are an alternative, but sowing of rehabilitated areas should immediately follow spreading in a native ecosystem, and cover crops should be considered to quickly establish cover to prevent erosion (Bell, 1996).

The addition of mulches (e.g. straw and hay) or sewage sludge (e.g. biosolids) to a rehabilitated area can increase the low water-holding capacity of coarse textured material (EPA, 1995; Bell, 1996; Johnston, 2000). Similarly, soils with poor internal drainage (containing high clay contents) can be improved by adding organic matter and deep ripping (Bell, 1996). Such factors can help establish microclimates for the successful germination and survival of seedlings, however, the application of such materials for large-scale rehabilitation is not usually feasible because of cost and supply (EPA, 1995). The use of these materials is usually limited to areas where rapid vegetation establishment is needed, or where significant soil or root amelioration is required (Minerals Council of Australia, n.d.).

3.7.2 Chemical Limitations and Rehabilitation Options

To rehabilitate areas, the root zone must be capable of supporting a self-sustaining vegetative cover and must possess chemical properties that are satisfactory for plant growth, which include an adequate nutrient supply, favourable pH, absence of toxic elements, low salinity and the microbial associations necessary for plant growth (Bell, 1996). Storing, stripping and replacing topsoil can affect the chemical status of topsoil. Nutrient requirements can vary depending on the desired landuse and need to be controlled with planned management strategies. High or low concentrations of a nutrient can have significant impacts on plant growth. Nutrient deficiencies in soil, overburden waste or tailings are generally easy to replenish, however, to correct nutrient deficiencies alone will often not produce satisfactory vegetation growth as other chemical factors such as pH, salinity or elemental toxicities may be present. Both acidity and alkalinity can be limiting factors, as soil pH will affect biological processes, plant nutrient availability and element release in quantities that are toxic to plant growth (Johnston, 2000). Acid conditions reduce nutrient availability (particularly calcium, phosphorus and molybdenum), induce metal toxicities, and promote enzyme inactivity in bacteria and fungi (Ashby *et al.*, 1989). Little plant growth occurs at $pH<5$ due to aluminium and manganese toxicity, while $pH>8.5$ can induce phosphate deficiency in plants and immobilise nutrients such as calcium, iron, copper, boron, zinc and manganese by affecting their sorption behaviour in the soil (Singer and Munns, 1996).

While a pH range of 6 to 7 is an optimal range for plant growth, Bradshaw and Chadwick (1980) state that most plant species can tolerate pH levels of 5-8. Soil toxicity from low pH can be decreased by the application of lime (calcium carbonate). Lime rates usually depend on soil type, source of lime and initial soil pH. Lime can be applied in the form of ground limestone, dolomite, agricultural lime or slaked lime to raise the rooting zone pH to a satisfactory level (Singer and Munns, 1996).

Nutrient deficiencies in topsoil can generally be overcome by fertiliser addition. The choice of fertiliser (i.e. inorganic or organic) and application rate will vary according to the site, soil type and the post-mining landuse. Field and glasshouse experiments are an important prelude in assessing potential nutrient deficiencies and amelioration strategies. Factors such as application rates, application methods (e.g. helicopters, tractors), rates of release and legume seeding to help with nitrogen fixation must be considered in relation to organic and inorganic fertilisers. For example, native ecosystems can be high in phosphorus already, however, soil mixing following handling can change the soil nutrient status. To rectify this deficiency, 10-80 kg/ha of elemental N and 5-80 kg/ha of elemental P have been used in rehabilitated areas with additional varying rates of potassium and micronutrients (EPA, 1995).

Brown and Grant (2000) suggest that the nutrient status of rehabilitated coal mines in the Hunter Valley can be improved by fertiliser application, grazing and burning. However, disadvantages can occur as a result of these management practices. Fertilisers can affect the roots of seedlings if it is placed too close to the plant and, in particular, fertilisers high in nitrogen can encourage weed growth, which can out-compete desirable species and become a fire hazard (EPA, 1995). Legume growth is favoured by relatively high phosphorus and low nitrogen fertilisers (EPA, 1995). For example, at the Ranger Uranium mine in the Northern Territory, native ground cover did not respond to fertiliser application, which instead encouraged the growth of dense grass cover and inhibited tree growth (EPA, 1995). While commercial inorganic fertilisers are generally most commonly used in mine rehabilitation, organic fertilisers such as biosolids (or sewage sludge) can be beneficial both as fertilisers and soil amendments.

Biosolids is a convenient amendment because it has many fertiliser constituents in one application (Reuter, 1997). Biosolids, the solid by-product of the wastewater treatment process, is obtained when water is removed from digested sludge. The moisture content of biosolids can vary depending on the digestion and dewatering methods used. Biosolids benefits include a source of organic matter and plant nutrients (e.g. nitrogen, phosphorus, potassium and micronutrients including boron, copper, iron, manganese and zinc), improvement to soil structure and increased microbiological development (Tisdale *et al.*, 1985; Phillips, 1994a). A number of research trials have been conducted on organic ameliorants that emphasised their potential use in mining rehabilitation (Phillips, 1994b; Parker and Grant, 2001). For example, Parker and Grant

(2001) found that biosolids application in rehabilitated areas in the Hunter Valley open cut coal mines has the potential to increase native and exotic grass species growth. However, biosolids use has many negative impacts and can result in the potential for heavy metal contamination and pesticide accumulation, which results in subsequent surface and groundwater contamination and increased weed growth (Phillips, 1994a). Therefore, it is essential that appropriate techniques be used to apply fertilisers and that effective management techniques be used to protect people, animals and the environment (Tisdale *et al.*, 1985).

The Environmental Protection Authority has produced guidelines for the use and disposal of biosolids products in Australia (EPA, 1997). The guidelines outline biosolids classes based on their chemical and physical composition. Biosolids supplied for mine site rehabilitation projects are typically greater than 20% total solids. Application area, pre-application soil analysis, and biosolids nutrient and contaminant levels, determine the rate of biosolids application (Tisdale *et al.*, 1985). Typical biosolids application rates are approximately 50 dry solid t/ha for mine site rehabilitation, although this is dependent on the state guidelines and contaminant levels (Phillips, 1994a; Deanne Pope pers comm., 2002). Hunter Water Corporation (HWC) biosolids products are tested and graded in accordance with the *Environmental Guidelines: Use and Disposal of Biosolids Products* (EPA, 1997).

Other research trials carried out on biosolids have compared crop performance, soil micro-organism viability and propagation, and sludge effective rates with other treatments (Reuter, 1997). Lindemann *et al.* (1984) compared soil treatment effects on soil micro-organism numbers and activity in New Mexico mine soils. Micro-organism growth was stimulated the most by organic amendments, and also led to the greatest increase in CEC and highest total N content. However, some negative aspects with sewage sludge use were evident, especially elevated metal levels. Sewage sludge use can become an issue when the post-mining use is a pasture ecosystem, making the metal accumulation in plants and uptake by grazing animals a potential concern. A Minnesota study of sludge application on agricultural land indicated that crops grown on sludge-amended soils took up negligible amounts of trace metals (Lindemann *et al.,* 1984). The study indicated an increase in C, N and extractable P accumulation in the treated soil. Sludge treated soils also maintained an optimal pH, which may be beneficial to alkaline soils. However, biosolids should not be applied to acid soils (<pH 6.0) unless some liming material is included in the land reclamation process, as metals in biosolids are more likely to be released creating problems for vegetation establishment (Phillips, 1994a).

3.7.3 Biological Limitations and Rehabilitation Options

Approximately 90% of soil organism activity occurs in the surface litter and the top 10 cm of the soil (King and Lobry de Bruyn, 2001). Soil micro-organisms, for example bacteria, fungi, algae, protozoa and actinomycetes, may have direct or indirect influences on plant growth, such as nutrient cycling and uptake, and nitrogen fixation (EPA, 1995; Bell, 1996). The symbiotic associations formed between plants and other organisms, such as *Rhizobium* bacteria and mycorrhizal fungi, can influence the nutrition and growth of plants (Bell, 1986). Hence, when soils are stripped and replaced, microbial activity can be markedly reduced (Bell, 1986; Bell, 1996). This reduction tends to be greater if topsoil is stockpiled rather than being directly returned (EPA, 1995; Bell, 1996). The most effective means to ensure that revegetation is not inhibited by a reduction in microbial activity is to replace topsoil after a minimum period of stockpiling and before the viability of these organisms decreases with time (Thurber Consultants *et al.,* 1990).

Some plant species may not establish until specific mycorrhiza have recolonised rehabilitated areas (EPA, 1995). The majority of native species used in rehabilitation probably form associations with vesicular arbuscular mycorrhiza (VAM) and ectomycorrhizal fungi (Bell, 1996). Mycorrhizal fungi can contribute a large component of soil biomass within topsoil and they make an important contribution to the success of revegetation by enhancing establishment and growth, increasing nutrient uptake, maintaining diversity and boosting the ability of mycorrhizal plants to compete for resources (Bell, 1996). This contributes to efficient recycling of nutrients and thus to the long-term stability of the revegetation. *Rhizobium* bacteria appear to be more tolerant of disturbance and stockpiling than mycorrhizal fungi (EPA, 1995). Soil microbial biomass can be used as a key parameter to monitor the successional development of rehabilitated sites because it is a key element in nutrient cycling and is very responsive to management changes.

Retention of viability of seed in topsoil depends on inherent dormancy, durability of the seed coat and response to moisture. Compaction or soil disturbance (e.g. topsoil removal and stockpiling) influences seed survival. The top 0-5 cm of soil contains most seeds and other plant propagules and, if this surface layer is not stripped separately, stockpile construction results in the dilution of the seed population within the stockpile (Grant *et al.* 1996; Koch *et al*, 1996). Survival of seed populations in stored soil depends on the vegetation present before soil stripping, seed characteristics of the species present, the location of the seeds in the stockpile (viability decreases with depth), the time the soil is stored (viability decreases with time), vegetation cover, and soil texture and moisture status during storage.

Where stockpiled topsoil is lacking in *Rhizobium* bacteria for legumes, the seed of the particular species can be inoculated with the appropriate strain prior to sowing (Bell, 1996). Seed inoculation with *Rhizobium* may be practically feasible, but can be prohibitively costly. An alternative is direct placement of fresh topsoil stripped from suitably vegetated sites. The addition of fresh topsoil onto areas rehabilitated with stockpiled soil can increase plant species richness, introduce microbes, lower bulk density and increase soil organic matter (Elliott and Reynolds, 2000). Fresh topsoil can be spread at a diluted rate or striped over only parts of pits to maximise the utilisation of the resource if availability is an issue. Dilution of fresh topsoil over stockpiled soil by striping has been successfully used in bauxite mining rehabilitation in Western Australia (Grant *et al.*, 2004).

If fresh soil is not available it may be possible to utilise a commercial inoculum or even develop one specific to the targeted ecosystem (Trappe, 1981). The benefits of microbial inocula include increased uptake of N, P, K and S, increased N_2 fixation, increased root longevity, drought tolerance and resistance to extreme temperatures (Killham, 1994). There are many factors that can affect the success of microbial inocula including considerations of strain selection, culturing of the strain, carrier preparation, mixing of the culture and carrier, maturation, storage, transport and application (Figure 3.6). Soil moisture and temperature in the rehabilitated area have a large impact on the initial success of microbial inocula, and both of these are influenced by soil type (Killham, 1994).

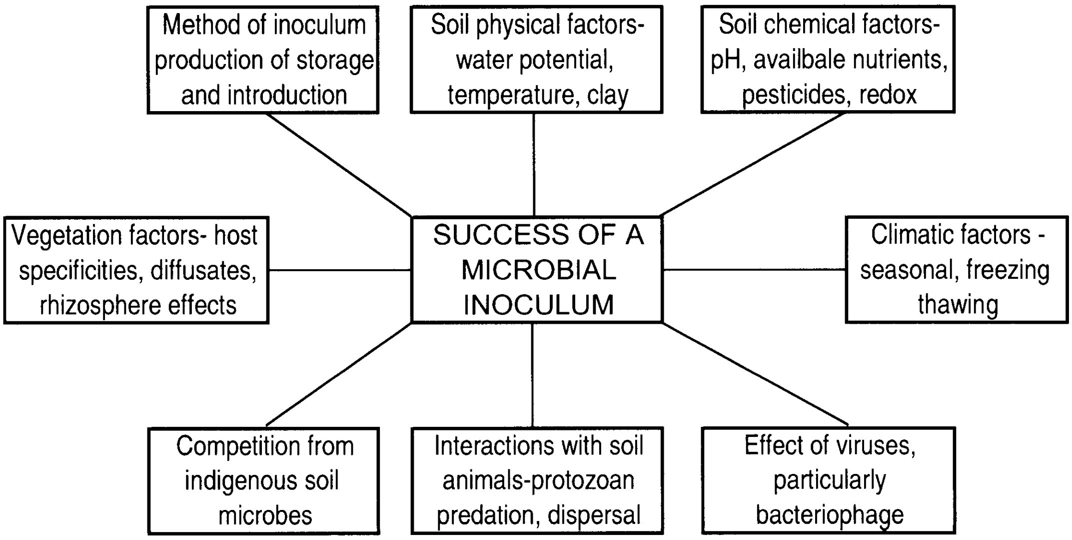

Figure 3.6: The main factors that determine the success of a microbial inoculum in soil (Killham, 1994).

3.8 MONITORING AND MANAGEMENT

It is generally regarded that pasture ecosystems become established a lot faster than other ecosystems. However, they need to be monitored and managed following rehabilitation to record characteristics that will lead to a self-sustaining ecosystem (EPA, 1995). Knowledge of the condition of the pre-mining land provides a guide to available post-mining landuse options. The state of the land, if documented, creates a benchmark for successful rehabilitation following mining (Bell, 1996). Baseline data are required before any disturbance to provide a control in relation to environmental systems whereby project impacts can be predicted and evaluated in the longer term (Allan and Southern, 1996). The initial vegetation establishment in a progressive rehabilitation plan is an important step, however, it does not guarantee a successful final landuse (Bell, 1996). Regular performance monitoring of these areas is an important component to ensure final landforms are physically and chemically stable under climatic variations, and that both the vegetation and landscape are evolving ecologically (McNamara *et al.*, 1998). Monitoring the nutrient cycle re-establishment in the area is particularly important for the long-term sustainability of rehabilitation (EPA, 1995). Rehabilitated ecosystems should change with time towards the structure and composition of the surrounding area (Grant *et al.*, 2001).

Completion criteria have been defined as rehabilitation performance objectives (EPA, 1995). Completion criteria that have been developed are usually based on vegetation indices measured at early growth stages or soil surface stability parameters based on landscape functional attributes (Elliott, 1996; Tongway, 1999). Certain issues need to be addressed and agreements made on the whether an area has been rehabilitated successfully. These include: what constitutes a viable ecosystem, what is an acceptable level of species diversity and how indistinguishable should a rehabilitated area be from neighbouring untouched areas (EPA, 1995). Defining completion criteria can aid in identifying successional pathways that ultimately lead to the rehabilitation objective. In Australia, limited recognised criteria exist to determine when rehabilitation is complete (Bell, 1996). However, Grant *et al.* (2001) recently developed a model that can assist the environmental monitoring programs in relation to end point criteria and successional pathways for manganese mining rehabilitation on Groote Eylandt, Northern Territory. A comprehensive assessment of vegetation composition and structure was undertaken and data collected were used to construct a successional trajectory that identifies sites heading towards the desirable end point ecosystem and sites that were not. Grant *et al.* (2001) states that this approach to defining successional development, completion criteria and indicators of success has potential to be applied to a wide variety of ecosystems and this approach may also be valid in the Hunter Valley.

Weed invasion control at rehabilitated coal mines in the Hunter Valley is important, in particular the noxious weed *Galenia pubescens*. This species successfully competes with sown species and can greatly reduce the success of a revegetation program (Hannan, 1995). Without adequate management, weed invasions and populations of domestic or wild grazing animals can slow down the success of revegetation (EPA, 1995).

CHAPTER 4.

Preliminary Survey of Topsoil Management in the Hunter Valley and Bowen Basin

4.1 INTRODUCTION

Current DIPNR guidelines in the Hunter Valley specify that topsoil should be stored in stockpiles that are ideally less than 60 cm in height but not exceeding a maximum depth of 3 m (Elliott and Veness, 1985; T. Voller, pers. comm., 2001). A previous study by Elliott and Veness (1985) that examined some physical and chemical effects of stockpiling topsoil at Mount Thorley and Cheshunt mines in the Hunter Valley were largely the basis for these guidelines. Anderson *et al.* (1988) also conducted a study on the effect of stockpiling topsoil on the physical, chemical and biological properties of two major soil types in the Bowen Basin, Queensland. These two studies currently represent the best available information on topsoil stockpiling in coal mining rehabilitation in eastern Australia.

Topsoil quality in the Hunter Valley is often poor and space for the construction of stockpiles is limited when compared to the Bowen Basin. No previous study has detailed topsoil management practices in the Hunter Valley and compared then to those in the Bowen Basin. Furthermore, previous studies in the Hunter Valley have only been conducted on a small number of the existing open cut coal mines that encompass a variety of soil types and other rehabilitation challenges. No study has compared topsoil management practices and their impact on physical, chemical and biological soil attributes across a large number of mine sites. The objective of this chapter was to compare topsoil management techniques in the Hunter Valley and Bowen Basin, and undertake a detailed preliminary survey of physical, chemical and biological characteristics of stockpiled soil across 12 mines in the Hunter Valley to identify soil deterioration resulting from stockpiling.

4.2 *METHODS*

4.2.1 Study Areas

Hunter Valley

Refer to chapter 2 (Study Site Description) for details of the Hunter Valley.

Bowen Basin

Approximately 20 open cut coal mines in the Bowen Basin are currently in operation, covering a geological structure of 32,000 km^2 of central Queensland, extending 550 km from Collinsville in the north to south of Theodore, having a range of 100 km east to west at its largest section (Roe *et al.,* 1996 - Figure 4.1). The climate of this region is subhumid and subtropical. The average rainfall is 625 mm, with a summer dominance (November to March). The region consists mostly of gently undulating to flat alluvial plains, undulating side slopes and upper reaches to steep mountain ranges. Most mining operations are located on the valley bottoms that are undulating (Roe *et al.,* 1996). Soils can be divided into three main areas in the Basin: sands to loams to lithosols on rocky ridges; podzolics, solodics and solodised solonetz on footslopes, lowlands and clay plains; and red, grey and black cracking clay soils on alluvials plains. Vegetation patterns found in the Basin are strongly related to soil type. However, a major proportion of the vegetation in the region has been cleared to improve agricultural value. Prior to mining activity, grazing for cattle was the main use and this landuse dominates in the eucalypt woodlands. The major economic bases for the region include farming, grazing and coal mining (Roe *et al.,* 1996).

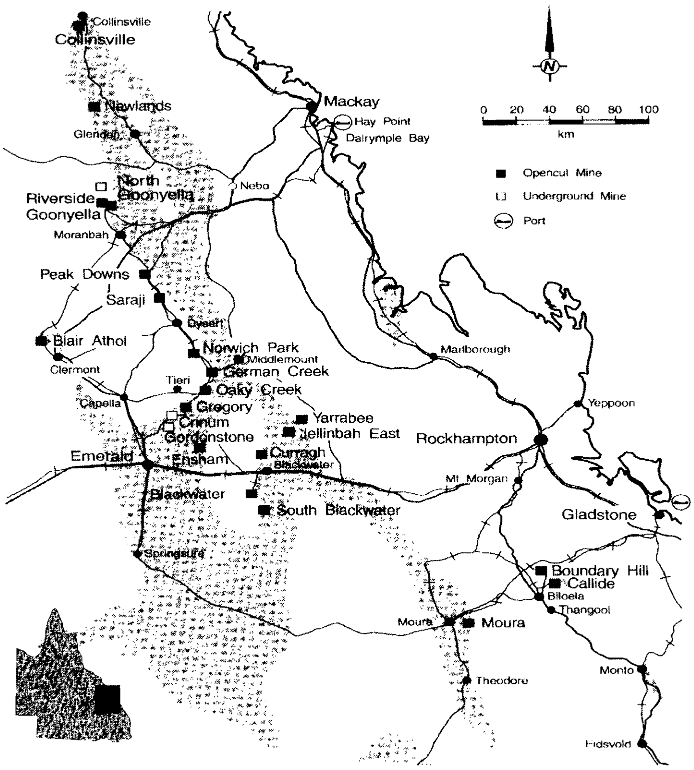

Figure 4.1: The location of the Bowen Basin in Queensland. Source: Roe *et al.* 1996. Shading indicates extent of coal in the region.

4.2.2 Hunter Valley Soil Collection

A preliminary survey of the Hunter Valley open cut coal mines was undertaken in April, 2000. Twelve mines were visited over five days namely, Bengalla, Cheshunt, Howick, Hunter Valley No.1, Liddell, Mt Arthur Coal, Mt Owen, Mt Thorley, Muswellbrook, Ravensworth, Rix's Creek and Warkworth (Appendix 4.1). Soil samples (150 in total) and topsoil information were collected from 25 stockpiles in total.

Three samples were collected from the top and sides of each of the 25 stockpiles at two depths using a soil auger (Figure 4.2). The depth of sampling chosen (0-0.2 m and 0.8-1 m) was governed by time and cost, to gather soil and topsoil information at a number of mine sites in the Hunter Valley. Samples for physical and chemical analyses were placed in a plastic bag, while samples for biological analyses were stored in 120 ml plastic containers. Soil for the biological analyses were stored in a portable insulated container in the field before being refrigerated at 4°C at the University of New England until they could be analysed. This maintained soil moisture and microbial activity. All chemical soil samples were air-dried at 30°C at the University of New England.

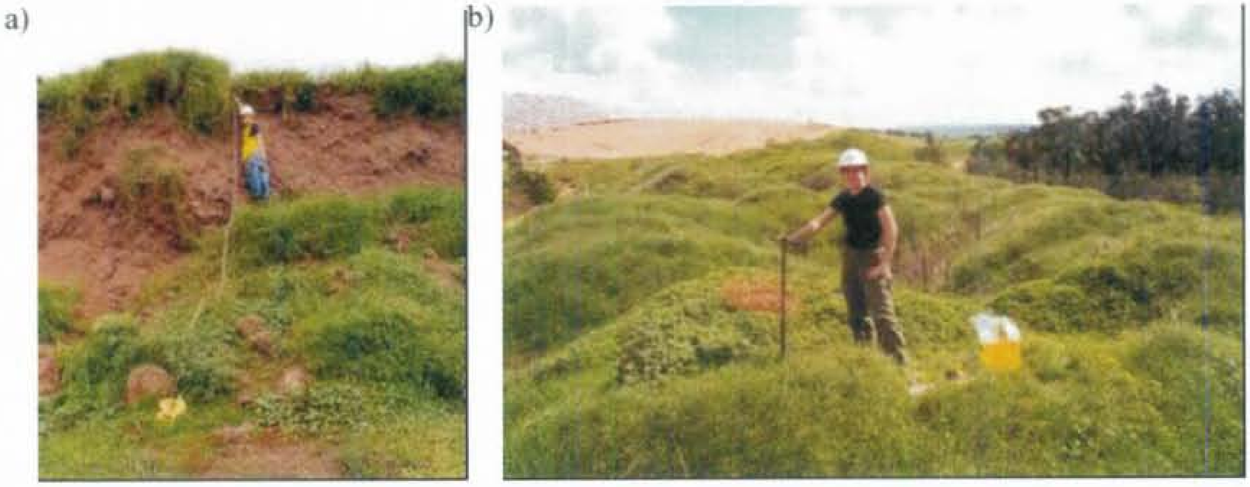

Figure 4.2: (a) Measuring stockpile height from a topsoil stockpile profile and (b) collecting samples with a hand auger at a topsoil stockpile in the Hunter Valley.

4.2.3 Soil Physical Analyses

Soil physical properties analysed were particle size analysis (PSA) and aggregate size distribution, Atterberg limits and coarse fragment distribution. Particle size analysis was based on the methods used by Day (1965) for the dispersion, sedimentation and sieving techniques for the fine earth soil samples measured. Clay (<0.002 mm), silt (0.002-0.02 mm), and sand (0.02-2.0 mm) were determined by sieving techniques on all samples taken. Atterberg limits were based on the methods used by Charman and Murphy (2000). Soil water content at the solid/plastic and plastic/liquid boundaries were measured.

4.2.4 Soil Chemical Analyses

Soil samples were analysed for pH, electrical conductivity (EC), loss on ignition (used to estimate soil organic carbon - SOC), total nitrogen (N), nitrate nitrogen (NO_3–N) and ammonium nitrogen (NH_4–N), total phosphorus (P), available P (Bray) and exchangeable cations (Ca, Mg, Na and K). Analyses of pH, EC, exchangeable cations and available P were based on methods outlined by Rayment and Higginson (1992). Analysis of total and available N were based on methods outlined in Page *et al.* (1982), while investigation of total P was conducted according to established analytical techniques described by Till *et al.* (1984). Finally, analysis of organic matter was based on procedures outlined in Moore and Chapman (1986). Prior to analysis, all soil samples were air-dried and passed through a 2 mm sieve.

Soil pH

The preparation of samples for pH analysis involved adding 10 g of soil sample to 50 ml of de-ionised water in a 250 ml plastic sample bottle. Bottles were then mechanically shaken end over end for 1 hour. After allowing 20-30 minutes for the soil to settle, pH was measured using a calibrated pH-meter (744 pH Meter Metrohm).

Electrical Conductivity

Electrical conductivity (EC) was measured by mixing 10 g of soil sample with 50 ml of de-ionised water in a 250 ml plastic sample bottle. Bottles were then mechanically shaken end over end for 1 hour to dissolve the salts. After allowing 20-30 minutes for the soil to settle, EC was determined by using a calibrated meter (EC meter, YSI model 30/10 FT, 30 Salinity Conductivity Temperature).

Soil Organic Carbon

The loss on ignition method was used to estimate the organic matter contained within a sample. The weight of each dry ignited porcelain crucible was recorded. About 1 g of soil sample was then added to each crucible and dried to a constant weight at 105°C and weighed again (initial weight). Samples were then ignited in a muffle furnace at 550°C and left for two hours. After igniting and cooling, they were reweighed (final weight). The organic matter content in a sample was calculated using the following formula:

$$\text{Soil Organic Matter \%} = \frac{\text{initial weight} - \text{final weight}}{\text{initial weight} - \text{crucible weight}} \times 100$$

Conversion of the soil organic matter (SOM) results to soil organic carbon (SOC), were calculated with the following assumption (Baldock and Skjemstad, 1999):

$$\text{SOM (g/kg soil)} = \text{SOC (g C/kg soil)} \times 1.72$$

Total Nitrogen

A soil sample (0.5 g) was weighed into a digestion tube and 10 ml Kjeldahl solution was added with 2-3 anti-bumping granules. The solution was mixed and then heated on a hotplate at 360°C for 2 hours. After allowing the tube to cool, de-ionised water was added to make a 75 ml solution. The solution was mixed and then left to clear. The clear solution was analysed using an Auto Analyser (Technicon Auto Analyser II).

Nitrate Nitrogen and Ammonium Nitrogen

A soil sample (5 g) was weighed into a 250 ml plastic sample bottle and 50 ml 2M KCl added. The bottles were then mechanically shaken end over end for 1 hour and left for 20-30 minutes to allow the solution to clear. The clear solution was filtered through Whatman number 1 filter paper and then passed through a reduction column. Finally, the extracted solution was analysed by using an Auto Analyser (Technicon Auto Analyser II).

Total Phosphorus

A soil sample (2 g) was weighed into a digestion tube and 10 ml of potassium dichromate in perchloric nitric acid mix (digestion mix) was added with 2-3 anti-bumping granules. The solution was mixed and heated on a hotplate at a low temperature (100°C). The temperature was gradually raised until white fumes ceased to be evolved from the tube (at approximately 150°C). Heating was then continued for approximately one hour at 190°C. After cooling, de-ionised water was added to the tube to make a 75 ml solution. The solution was then mixed and allowed to stand overnight. The clear solution (minus settled particulate matter) was then transferred to a sample bottle for analysis by ICP (Model 3560B ARL).

Available Phosphorus

Available phosphorus was determined by the fluoride extractable method (Bray 1). Initially, 7.14 g of soil was mixed with 50 ml 0.03M NH_4F in 0.025M HCL extracting solution in a 250 ml sample bottle. After hand-shaking for 60 seconds, bottles were placed in a centrifuge for 10 minutes, allowed to settle and then filtered through Whatman number 1 filter paper to obtain clear extracts. A 10 ml sample of clear extract was then mixed with 8 ml of colour reagent and diluted to 100 ml with de-ionised water. Standard samples were prepared at a concentration of 0, 7, 14, 21, 28 and 35 ppm respectively. Phosphorus concentrations were then read using a UV visible spectrophotometer (Varian DMS 80 model).

Exchangeable Cations

Exchangeable cations analysed were Ca, Mg, Na and K. These cations were extracted from the soil samples by mixing 5 g of each soil sample with 100 ml of 1M NH_4Cl (at pH 7) and mechanically shaking end over end at approximately 25°C for 1 hour. The solutions were then filtered through Whatman number 1 filter paper and analysed by Inductively Coupled Plasma

(ICP - Model 3560B ARL). Soil exchangeable cations (in mg/kg) were converted to cmol$_+$/kg according to the atomic weight of the cation (e.g. 390 mg/kg for K, 200 mg/kg for Ca, 120 mg/kg for Mg and 230 mg/kg for Na).

Other Calculated Parameters

Effective Cation Exchange Capacity (ECEC) was calculated using the following equation:

$$\mathrm{ECEC} = [\mathrm{Na}] + [\mathrm{K}] + [\mathrm{Mg}] + [\mathrm{Ca}]$$

where ECEC and exchangeable cation concentrations are in units of cmol$_c$/kg. Because the soils all had neutral or alkaline pH, exchangeable aluminum could be assumed to be negligible.

4.2.5 Soil Biological Analyses

The biological activity in soils was estimated by measuring microbial respiration (CO_2), richness and density of topsoil seed stores. Microbial activity in the soil from each site was estimated by measuring respiration using the carbon dioxide mineralisation determination method (Howarth and Paul, 1994). This involved incubating soil with a separate vial of potassium hydroxide (KOH - 2.0 M) for 7 days at 25 °C with 24 hours darkness in an airtight container (Figure 4.3). Soil was sieved with a 4 mm sieve, as this has been found to cause the least damage to the soil microbial population (Jenkinson and Powlson, 1976). Fifty grams of dry sieved soil was placed in a petri dish, wetted up and left to equilibrate for three days before being incubated. The soil was placed into a container with a 1 ml vial of KOH and sealed. The KOH then reacted with the CO_2 produced and was measured by back titration against HCl (0.1 M). This method has been identified as the most effective for sampling overall microbial activity in regenerating soils on coal spoils (Hersman and Temple, 1979).

Topsoil seed stores were measured by placing soil to a depth of 2.5 cm in 15 cm x 10 cm seed trays and recording species germination in a temperature controlled glasshouse at the University of New England. The seed trays were monitored at four and 12 weeks for the number of emergents (seed density) of each species (Figure 4.4). Species that could not be identified immediately were potted on for further identification. Maximum and minimum temperature was monitored on a weekly basis and water levels recorded. Water rates were controlled with an automatic timer to mimic Hunter Valley conditions. No heat treatments were applied to the seed stores as the pasture grasses within the area are unlikely to be burnt as a management option for rehabilitation methods on the mine sites.

Figure 4.3: Biological incubation chamber, with topsoil and KOH in the clear vial.

Figure 4.4: Topsoil seed stores estimated from germination in trays in a glasshouse at the University of New England.

4.2.6 Bowen Basin Topsoil Management

For comparison to the detailed analyses in the Hunter Valley data on topsoil management activities in the Bowen Basin were collected through a questionnaire. The questionnaire was distributed to approximately 20 open cut coal mines in the Bowen Basin. The questionnaire related to 11 parameters important to topsoil stockpiling (Appendix 4.2). Along with the questionnaire, detailed information was also requested on five existing stockpiles. Overall, five mines responded (Burton Coal, Callide, Curragh, Peak Downs and South Blackwater), giving a total of 60 stockpiles. In addition, three mines (German Creek, Moura and Peak Downs) provided general topsoil management documentation. These data have been summarised in Appendix 4.3. This allowed a comparison between topsoil stockpiling techniques in the Bowen Basin and the Hunter Valley.

4.2.7 Data Analyses

The comparison between topsoil stockpiles in the Bowen Basin and Hunter Valley differ in the numbers of stockpiles sampled, 60 and 25 stockpiles, respectively. Also, while the Hunter Valley data involved direct field measurements, the Bowen Basin data were compiled from a questionnaire. All data were tested for equal variances and normal distributions. Data that were non-normal were transformed using log or square root transformations. A total of 18 physical, chemical and biological parameters were tested across six factors (height, age, depth, vegetation cover, seeding and site). Height and age were analysed using both regression analysis and one- and two-way ANOVA. Height and age classes were chosen based on the means of the stockpile data collected from the 12 mine sites (0-2, 2-4, 4-6 and > 6 m or years). Depth of sample (0-20 cm and 80-100 cm), seeding (+ or -) and site (12 mines) were analysed using one- and two-way (with age and height class) ANOVA. Vegetation cover was analysed using regression analysis. Three-way ANOVAs were not undertaken, as it was believed that possible interactions were not ecologically meaningful. Only data for factors, interactions or soil characteristics that were significant are presented. Tukey's multiple range test was used to examine post-hoc differences when the ANOVA was significant. All analyses were conducted using the Statgraphics^{TM} program. Atterberg limits of collected soils are not shown as they were found to be non-significant. All reported topsoil seed store densities were based on numbers per sample. Refer to Appendix 4.4 for units associated with physical, chemical and biological parameters measured.

Multivariate analysis was performed on the topsoil seed stores (species richness and seed density) through ordination techniques. All unknown species were included for species richness ordination techniques, however, when broken into origin, the unknown species were eliminated. Ordinations were carried out using Detrended Correspondance Analysis (DCA) in the CANACO^{TM} application. Analysis of Similarity (ANOSIM) was performed using the program PRIMER with Bray-Curtis similarity matrices with a maximum of 10,000 permutations.

4.3 RESULTS AND DISCUSSION

4.3.1 Comparison of Stockpile Characteristics in the Hunter Valley and Bowen Basin

Within the Hunter Valley, over 50% of the topsoil stockpiles were between 2 and 4 m in height, with 60% being greater than the 3 m DIPNR guideline (Figure 4.5). The Hunter Valley mean height was 3.8 m with a range from 1 m to 9.5 m. In contrast, the Bowen Basin had 28% of its topsoil stockpiles greater than 3 m, with a mean height of 2.8 m (Figure 4.2). The range was from 0.9 m to 11 m in height. Similarly to the Hunter Valley, over 50% of the topsoil stockpiles occurred between the 2 to 4 m height interval.

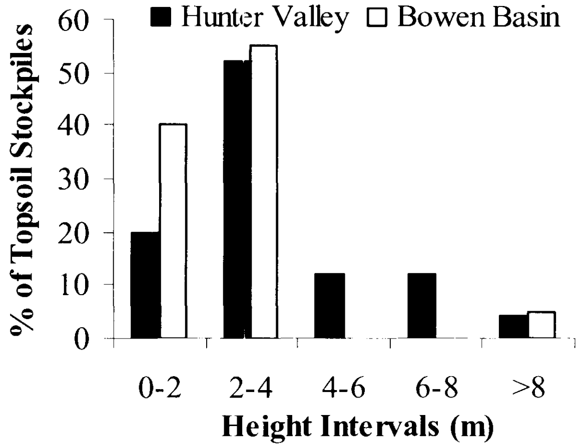

Figure 4.5: Percentage of topsoil stockpiles in various height intervals in the Hunter Valley and Bowen Basin.

Within the Hunter Valley, the topsoil stockpiles ranged from fresh to 10 years old, with a mean age of 3.2 years (Figure 4.6). Bowen Basin stockpiles tended to be older than those in the Hunter Valley, with a range from 1 to 10 years old and a mean of 5.8 years. The Hunter Valley had 30% of the stockpiles less than one year old, while the Bowen Basin had only 8%. Both regions, however, have a large proportion of topsoil stockpiled for long periods of time.

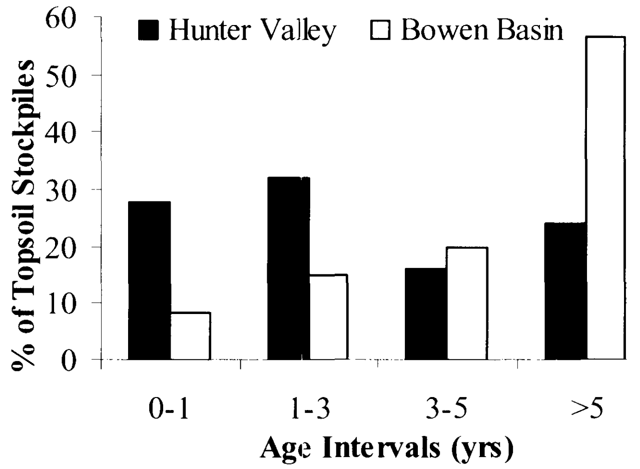

Figure 4.6: Percentage of topsoil stockpiles in various age intervals in the Hunter Valley and Bowen Basin.

The mean volume of a stockpile in the Hunter Valley was 15,620 m^3 with a range from 250 m^3 to 65,488 m^3. Within the Hunter Valley, over 50% of the topsoil stockpiles were less than 10,000 m^3 (Figure 4.7). The Bowen Basin, however, had 67% of its topsoil stockpiles greater than 40,000 m^3, with a mean volume of 80,880 m^3 and a range from 6,200 m^3 to 305,000 m^3 in volume. Overall, the Bowen Basin stockpile volumes tended to be much greater, which is indicative of the limited land space in the Hunter Valley.

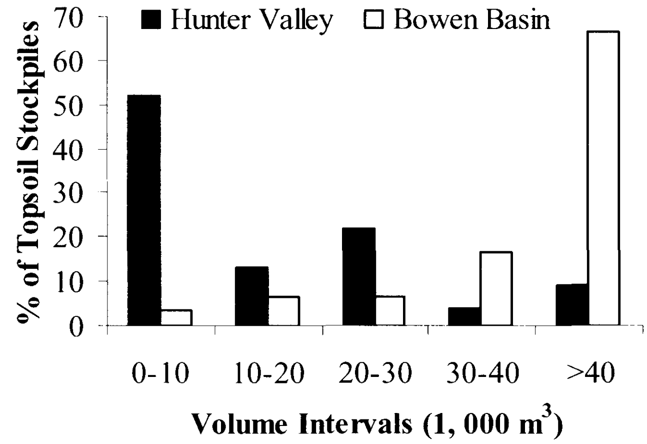

Figure 4.7: Percentage of topsoil stockpiles in various volume intervals in the Hunter Valley and Bowen Basin.

The Hunter Valley mean stockpile area was 4,413 m^2 with a range from 100 m^2 to 16,000 m^2. Within the Hunter Valley, over 80% of the topsoil stockpiles occurred in the less than 10,000 m^2 interval (Figure 4.8). The Bowen Basin, however, had 33% of its topsoil stockpiles greater than 40,000 m^2, with a mean area of 30,488 m^2 and a range from 2,873 m^2 to 100,000 m^2. Overall, the Bowen Basin topsoil stockpile areas, like volumes, are much greater, indicative of the limited land space in the Hunter Valley. Differences are related to the area available for stockpiling and the not disturbed areas of land, as current coal production in the two regions is comparable (Hunter Valley contributes 58 Mt/year and the Bowen Basin contributes approximately 87 Mt/year).

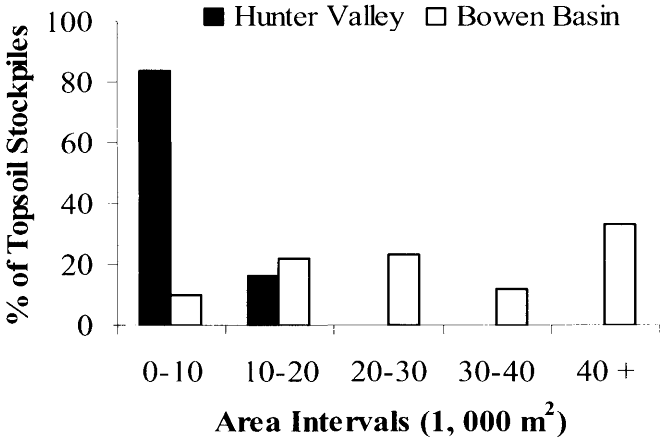

Figure 4.8: Percentage of topsoil stockpiles in various area intervals in the Hunter Valley and Bowen Basin.

4.3.2 Seeding and Vegetation Cover

Within the Hunter Valley, only 24% of the topsoil stockpiles were seeded. Information was not available on seeding and vegetation cover for the Bowen Basin. Nonetheless, in the Hunter Valley, 60% of the topsoil stockpiles had 80-100% vegetation cover (Figure 4.9). The Hunter Valley mean stockpile vegetation cover was 71.8% with a range from 0 to 100%.

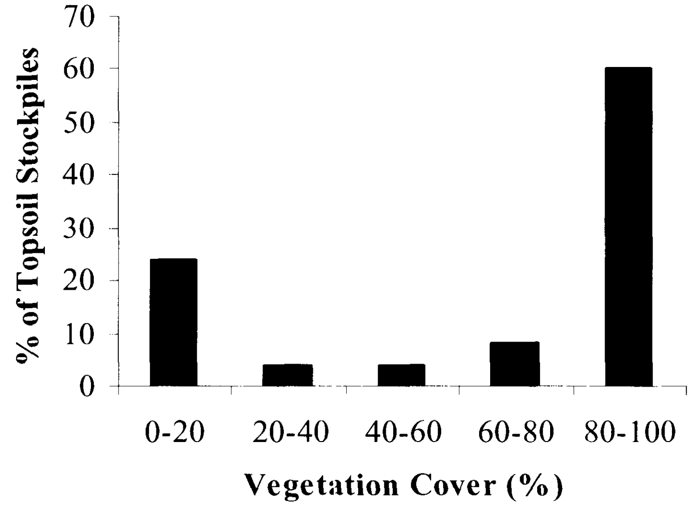

Figure 4.9: Percentage of topsoil stockpiles in various vegetation cover intervals in the Hunter Valley.

There was a significant logarithmic correlation between stockpile age and vegetation cover (R^2=0.44, P<0.0001; Figure 4.10). Seeded stockpiles established a vegetation cover more rapidly than non-seeded stockpiles. Although most stockpiles had high vegetation cover after two years, significant erosion could occur over this period of time. Stockpiles should be seeded with a pasture/legume mix, to rapidly establish vegetation cover to reduce erosion, replenish seed stores and maintain biological activity.

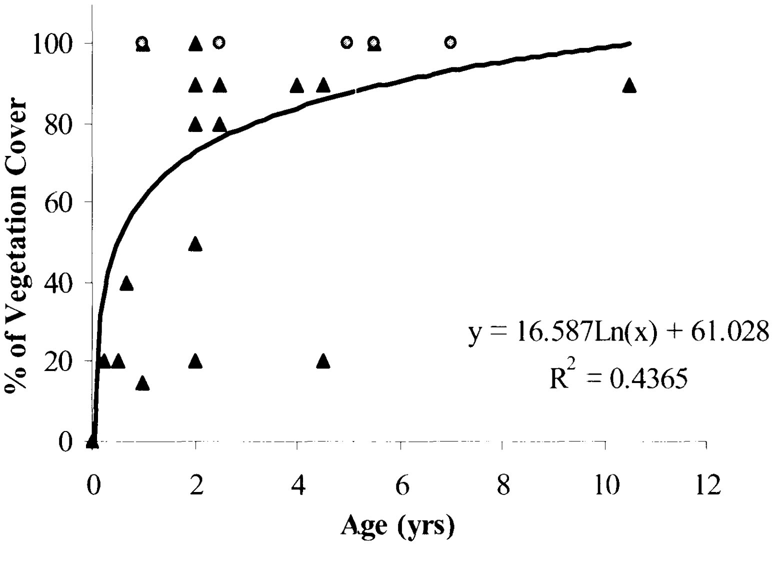

Figure 4.10: Relationship between age and topsoil stockpile vegetation cover for seeded (circles) and unseeded (triangles) stockpiles in the Hunter Valley.

4.3.3 Soil Parameters across Hunter Valley Mine Sites

Of the three stockpile, two physical, 13 chemical and three biological parameters tested across the 12 mine sites (21 tests), 13 showed significant differences between sites (Table 4.1). Height was the only stockpile characteristic that varied significantly across the mine sites. Ten chemical, one physical and one biological parameters differed significantly across the mine sites (Table 4.1, Appendix 4.5), indicative of the variable topsoil resources that exist on coal mines throughout the Hunter Valley. This results from the variable geology and topography that has led to the formation of a variety of soil types ranging from gravelly lithosols on the ridges, upper slopes of red and brown podzolics, and lower slopes of yellow solodics. Soil type variability was indicated in the current study by significant variation in sand percentages across the sites (Figure 4.11a). An example of chemical variability is provided by examining total N and K, which differed significantly across the 12 mine sites (Figure 4.11b and c). Chemical variability may lead to different rehabilitation operations being employed after topsoil stockpiling. For example, sites with lower total N stores may require increased seeding rates of nitrogen fixing species.

One of the objectives of the preliminary study was to sample topsoil stockpiles across the range of variability and identify key processes affected by stockpiling throughout the Hunter Valley. Results indicate that sampling was successful in taking into account this variability, and the rest of this chapter will focus on significant relationships regarding interactions across all sites.

Table 4.1: Summary of soil parameters across mine sites. *** = $P<0.001$, ** = $P<0.01$, * = $P<0.05$, ns = not significant, n/a = not applicable. Based on the recommendations by Charman and Murphy, 2000; Perverill *et al.*, 1999.

Parameters and Stockpile Attributes	P	Range	Recommended Level	Actual Levels
Height (m)	**	1.95-6.83	3	n/a
Age (yrs)	ns	0.66-5.00	n/a	n/a
Volume (m^3)	ns	3,121-33,062	n/a	n/a
Sand (%)	***	26.9-69.2	n/a	n/a
Silt and Clay (%)	ns	1.6-11.7	n/a	n/a
pH (w1:5)	ns	7.00-8.88	7	alkaline
EC (dS/m)	***	0.15-0.89	< 0.4	moderate
SOC (%)	***	0.33-1.43	> 2%	low
Na (cmol(+)/kg)	*	0.4-3.5	0.2-2.0	moderate
Ca (cmol(+)/kg)	***	1.5-20.0	2.0-18.0	moderate
K(cmol(+)/kg)	***	0.3-1.8	0.05-1.00	moderate
Mg (cmol(+)/kg)	***	2.8-13.1	0.3-1.0	moderate
ECEC (cmol(+)/kg)	***	5.3-34.4	n/a	n/a
Total N (%)	***	0.05-0.19	0.05-0.30	moderate
Total P (mg/kg)	***	144-365	200-1500	low
Avail P (mg/kg)	ns	1.23-6.77	4-20	low
NO_3-N (mg/kg)	*	11.3-44.7	>20	high
NH_4-N (mg/kg)	ns	2.7-31.5	n/a	n/a
Microbial Respiration CO_2 (mg/kg)	ns	4.9-19.7	n/a	n/a
Species Richness (per sample)	ns	4.2-9.3	n/a	n/a
Seed Density (per sample)	*	8.0-37.3	n/a	n/a

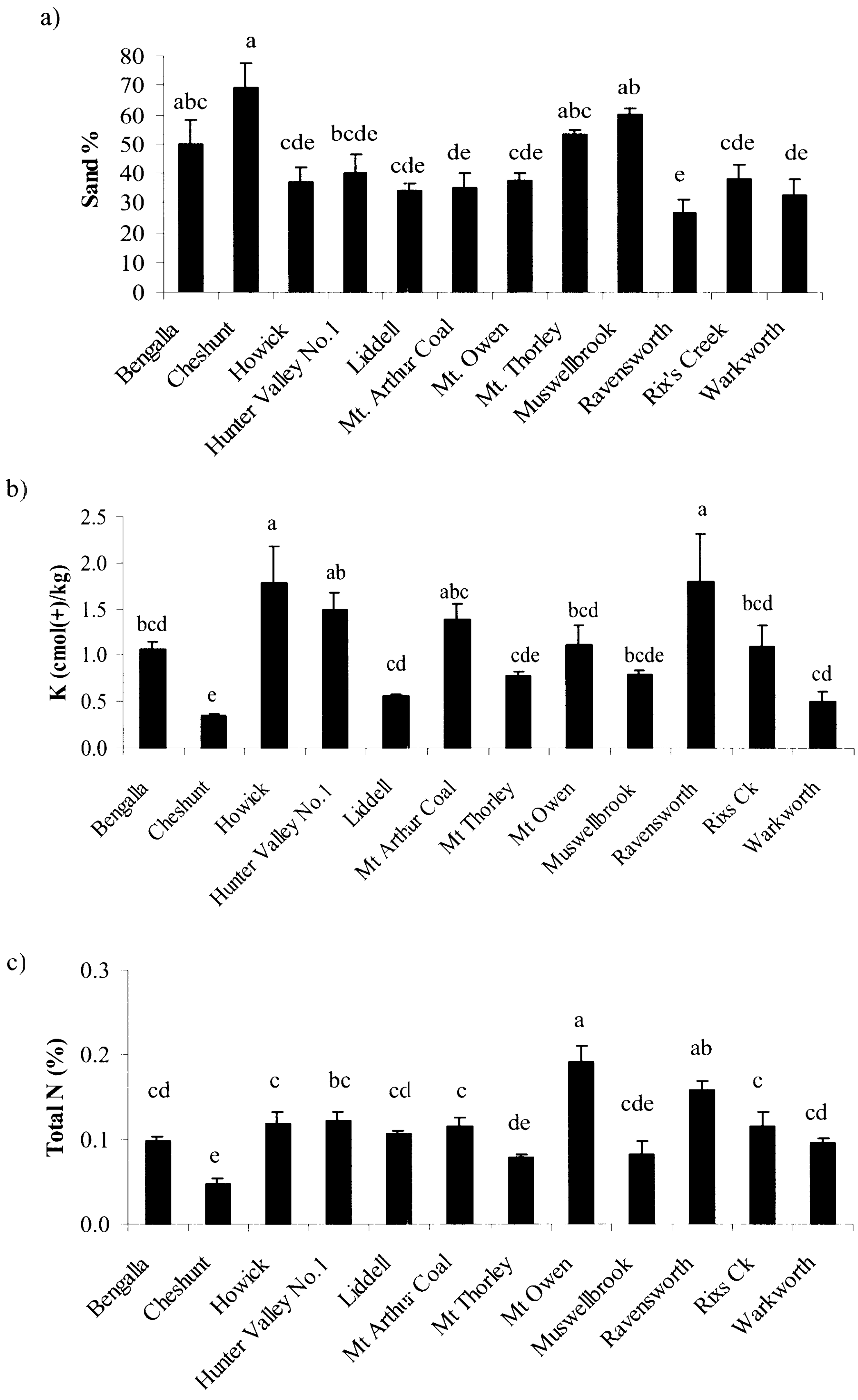

Figure 4.11: (a) Sand percentage (b) K and (c) total N across mine sites (Mean +/- Standard Error of the Mean). Different letters refer to significantly different values within each soil parameter determined from Tukeys post-hoc test, a: corresponds to the highest value.

4.3.4 Summary of Soil Parameters across Stockpile Attributes

Of the two physical, 13 chemical and three biological parameters tested across the six stockpile attributes (height and age both regression and ANOVA-144 tests), only 20 significant effects were recorded (Table 4.2). While there were two significant regressions for height, there were no significant ANOVAs for height class. In contrast, two significant correlations for age and eight significant ANOVAs for age class were exhibited. Only two of the age soil parameters (Ca and K) were significant for both correlation and ANOVA. These relationships are most likely to be the strongest as they are robust to different statistical analyses. Vegetation cover exhibited two significant correlations while depth class had six significant ANOVAs. While chemical parameters had the greatest number of significant tests across the stockpile attributes (13 out of 20), this represented only 13% of the tests performed compared to 17% for biological and 13% for physical. Significant results are presented for one example of similar patterns and are discussed in more detail in the following sub-sections.

Table 4.2: Summary of statistical results for stockpile characteristics across all chemical, physical and biological parameters. The significant results have an asterisks where *** P<0.001, ** P=<0.01, *P=<0.05, and non significant results are presented as blanks.

Parameters	Height	Age	Age Class	Vegetation Cover	Depth Class
Silt and Clay			*		**
EC			*		
Na	*(-ve)				*
Ca	***(+ve)	*(+ve)	**		
K		*(+ve)	**	*(+ve)	
ECEC			*		
Avail P			*		
Total P			***		
NO_3-N					***
NH_4-N					*
Microbial Respiration			*	*(+ve)	
Species Richness					***
Seed Density					**

4.3.5 Physical Parameters

The Particle Size Analysis (PSA) mean silt and clay percentage was significantly higher in the lower depth of 80-100 cm than the 0-20 cm soil depth ($F_{1,48}$=11.8, P=0.001). Movement of fine particles from the surface to within the stockpiles lower depths was evident, probably indicating weathering and subsequent wind or water erosion. The PSA mean silt and clay percentage was significantly higher from 2-4 years than any other age class, with the lowest silt and clay percentage found at 0-2 years of age ($F_{3,46}$=3.47, P=0.024; Figure 4.12). A significant interaction was exhibited between age class and depth with the 80-100 cm sample at 2-4 years of age having a significantly higher silt and clay percentage than expected ($F_{3,42}$=3.78, P=0.017; Figure 4.13).

Beyond four years, the silt and clay material has probably been moved below the maximum sampling depth of 1 m. However, processes such as clay illuviation could be occurring, where the deposition of clay in the lower horizons of a soil is the result of its removal from upper horizons through eluviation (downward removal of soil material in suspension or in solution - Charman and Murphy, 2000). Usually this process takes years to develop, especially in alluvium soils, so the relationship that is present could be a result of the types of materials used when the stockpiles were constructed and the weathering taking place over the years by water and wind erosion (P. Lockwood, pers comm., 2002).

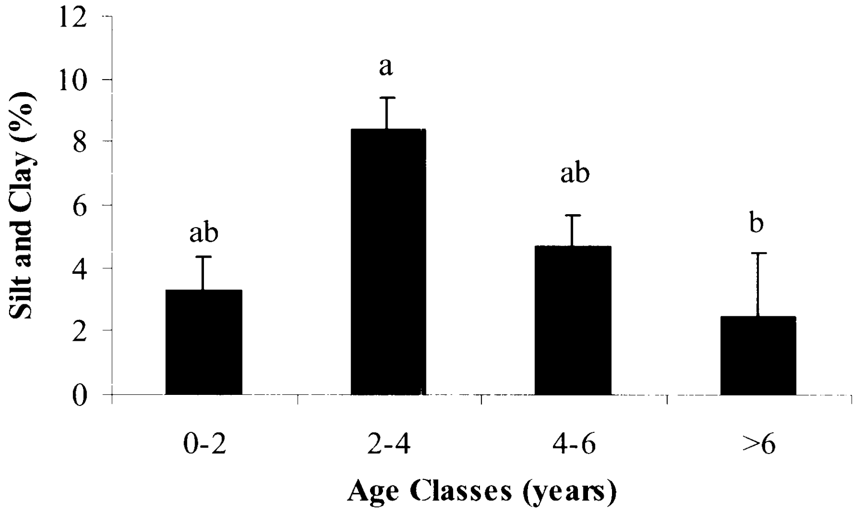

Figure 4.12: Percentage of silt and clay across stockpile age classes (Mean +/- Standard Error of the Mean). Different letters refer to significantly different values determined from Tukeys post-hoc test.

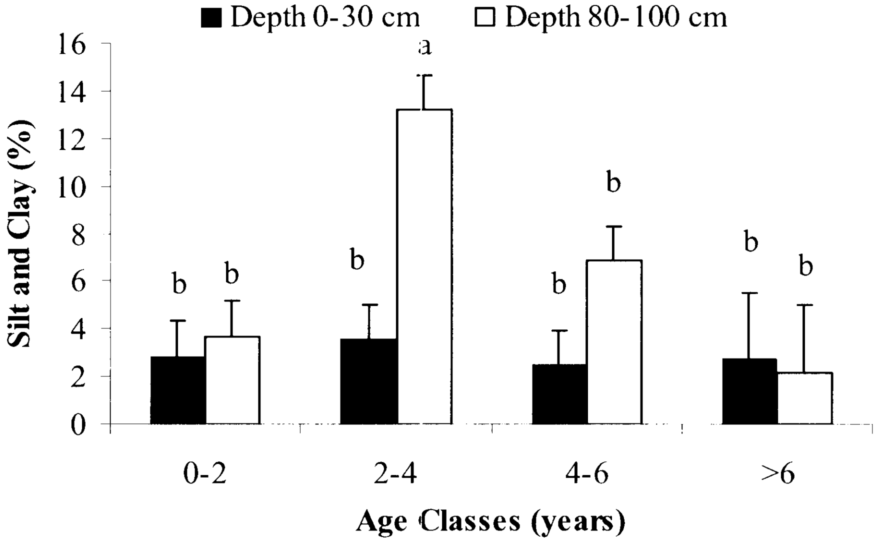

Figure 4.13: Interaction between age classes and depth for silt and clay percentages (Mean +/- Standard Error of the Mean). Different letters refer to significantly different values determined from Tukeys post-hoc test.

4.3.6 Chemical Parameters

Electrical Conductivity

Electrical conductivity (EC) of topsoil was significantly higher in the age class >6 years, in comparison to all other age classes ($F_{3,46}$=3.22, P=0.031). In comparison to recommended values, all topsoil exhibited acceptable EC levels (Appendix 4.5). To ensure vegetation growth is not impeded EC values should be less than 1.5 dS/m (depending on plant species and soil texture), as EC values are an index of soluble salt levels (Elliott and Veness, 1981). The differences in EC across age class are related to the older stockpiles having a greater vegetation establishment causing increased mineralisation of organic matter associated with stockpiling. Moisture due to rainfall at the surface of the older stockpiles could have generated microbial activity and increased the organic matter mineralisation. The observed differences in soil parameters could be driven by inherent differences in the soil types across the 12 mine sites (see Table 4.1). Regardless, where possible the results and discussion are assuming that this is not the driving force for observed patterns and explanatory processes are proposed for all other parameters.

Exchangeable Cations

Sodium levels were significantly higher at 80-100 cm than the surface ($F_{1,48}$=5.91, P=0.019; Appendix 4.5). This probably resulted from the displacement of Na by other cations at exchange sites followed by leaching of Na through the stockpile. Sodium will rise through capillary processes if saline groundwater rises, but the elevated nature of stockpiles suggests that leaching would be the dominant process. High ESP and EC can influence the reaction of topsoils and subsoils to Na, possibly leading to degradation of soil structure as a result of dispersion (Rengasamy and Churchman, 1999). Deterioration in the physical condition of soils can induce many negative impacts on vegetation establishment, including waterlogging, surface crusting and hard setting. This can result in problems such as poor infiltration, reductions in plant available water capacity, poor seedling emergence, poor aeration (hence poor root development), poor leaching and an associated build up of toxic elements (Shaw, 1999). Sodium levels were negatively correlated to stockpile height ($F_{1,48}$=4.37, P=0.042). This most likely resulted from increased leaching in larger stockpiles due to increased elevation or an altered balance between leaching and capillary rise.

Calcium was positively correlated to height ($F_{1,48}$=8.99, P=0.004) and age ($F_{1,48}$=4.84, P=0.033). This is indicative of Ca mineralisation following decomposition of plant residues after establishment of vegetation on the topsoil stockpiles. This process is accelerated at the high pH values (pH 8-9) of these soils. Calcium is mineralised because high pH promotes the formation of carbonates that precipitate with Ca as $CaCO_3$ (Singer and Munns, 1996). This pattern was also observed for age class ($F_{3,46}$=4.45, P=0.008; Figure 4.12), but not height class.

Figure 4.12: Calcium concentrations across age classes (Mean +/- Standard Error of the Mean). Different letters refer to significantly different values determined from Tukeys post-hoc test.

Potassium, like Ca, increased with age of stockpiles. Potassium levels were significantly higher in the >6 year age class ($F_{3,46}$=4.44, P=0.008). The total amount of K found in soils is a function of the parent material, extent of weathering and leaching of soil minerals, type of clay minerals, soil texture, organic matter and K fertilisers (Gourley, 1999). The older stockpiles may have conditions that are more favourable to K availability, when compared to lower age classes. Potassium levels were also positively correlated to vegetation cover ($F_{1,48}$=4.70, P=0.035) Potassium may not be as easily leached when pasture species develop high vegetative cover. Leaching losses can be reduced by not fertilising in excess or fertilising at particular times of the year (Singer and Munns, 1996). Calcium mineralisation in older stockpiles led to significantly higher ECEC in older compared to younger topsoil stockpiles due to a greater vegetative cover than younger stockpiles ($F_{3,46}$=3.11, P=0.035).

Phosphorus and Nitrogen

Available P was significantly higher in the >6 years age class than the 0-2 and the 4-6 year age classes ($F_{3,46}$=2.93, P=0.044; Figure 4.13). Total P levels were also significantly higher in >6 year-old stockpiles ($F_{3,46}$=8.64, P=0.0001). This indicates that available and total P levels decrease when topsoil is originally stockpiled, due to the dilution of the A1 horizon when mixed with the A2 and B horizons. Mineralisation is a slow fixed reaction, and is responsible for the decrease in availability of P for plant uptake, which is observed with increasing age, and/or temperature of contact between P and soil. When this process occurs, P is replenished primarily by diffusion (Barrow, 1974). Total P, however, could be high as a result of established vegetation cover, since organic matter tends to accrue, and net mineralisation of P from the microbial biomass and organic residue pools may be a significant source of P, where it will be then used in plant uptake (Moody and Bolland, 1999). Soil factors such as pH, CO_2, partial pressure, enzyme activity, cation and anion activities, and its processes in the rhizosphere zone determine the immediate availability of P to the plant root (Moody and Bolland, 1999).

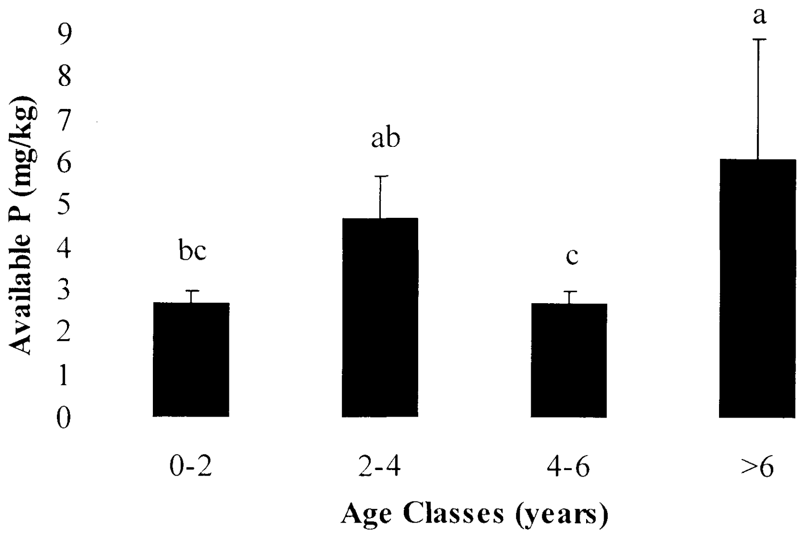

Figure 4.13: Available P across age classes of the topsoil stockpiles (Mean +/- Standard Error of the Mean). Different letters refer to significantly different values determined from Tukeys post-hoc test.

Nitrate-N and NH_4-N levels were significantly greater in the 80-100 cm depth class ($F_{1,48}$=16.3, P=0.0002; $F_{1,48}$=5.48, P=0.023, respectively; Appendix 4.6). Nitrate-N is more readily leached than NH_4-N because it is negatively charged and not affected by the availability of exchange sites. Ammonium-N may accumulate due to anaerobic conditions and to denitrification of NO_3-N within the core of stockpiles (at lower depths). However, when the stockpiles are respread, NH_4-N is rapidly oxidised to NO_3-N in rehabilitated areas (Williamson and Johnson, 1990a). Therefore, the leaching of N compounds in stockpiles may not be a major problem, and available N levels can be increased through the application of fertiliser or using nitrogen-fixing species in the rehabilitation process. Leaching is a major problem when combined with denitrification. Nitrogen at the surface mineralises out of organic matter, creating NH_4-N that is nitrified to NO_3-N under aerobic conditions. Nitrate-N then leaches rapidly into the anaerobic zone, where it is lost as di-nitrogen (N_2) and nitrous oxide (N_20) by denitrification (Singer and Munns, 1996).

4.3.7 Biological Parameters

Microbial respiration was positively correlated to vegetation cover ($F_{1,48}$=4.86, P=0.032) and significantly higher in the 2-4 year age class ($F_{3,46}$=2.99, P=0.041; Figure 4.14). Microbial respiration was probably reduced as a result of soil disturbance during stockpile creation (Visser *et al.*, 1983), increased as vegetation cover was established and subsequently decreased in older stockpiles as the anaerobic zone becomes more extensive. All stockpiles should be seeded with a pasture mix or cover crop to maintain microbial activity in the soil.

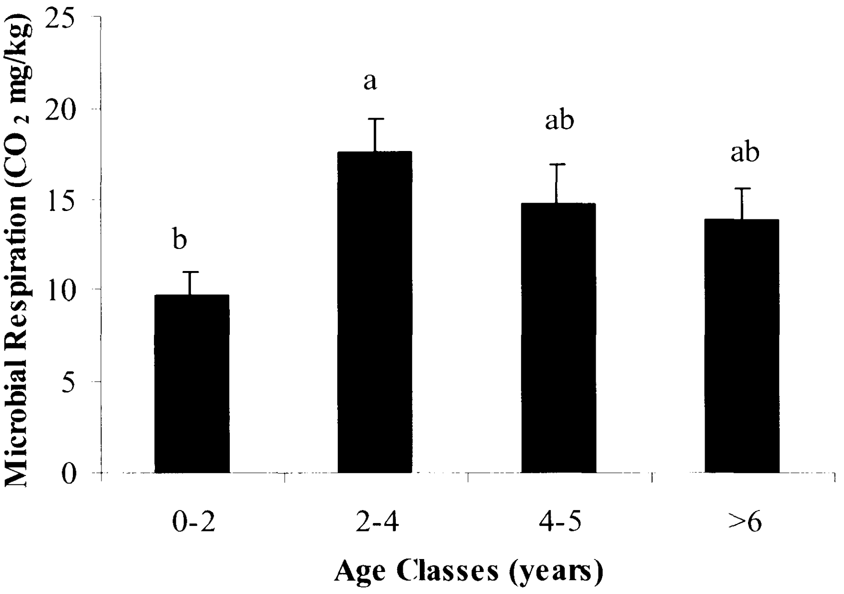

Figure 4.14: Microbial Respiration CO_2 (mg/kg) across age classes of the topsoil stockpiles (Mean +/- Standard Error of the Mean). Different letters refer to significantly different values determined from Tukeys post-hoc test.

Topsoil seed stores species richness and seed density were significantly higher in the 0-20 cm depth class ($F_{1,48}$=24.7, P<0.0001; $F_{1,48}$=7.00, P=0.0110 respectively). This indicates that seed reserves are lost at depth probably as a result of seed decay under anaerobic conditions. Thurber Consultants *et al.* (1990) concluded that the survival of seed populations in stored soil depends on the number of species and seeds present before stripping, seed characteristics (dormancy period and seed coat) of each species, location of seeds in the stockpile (viability decreases with depth), time of topsoil stockpiling (viability decreasing with time), vegetation cover during storage and soil texture and moisture status during storage.

Ordinations (Detrended Correspondence Analysis - DCA) based on the topsoil seed store separated stockpiles according to mine site (Figure 4.15). The ANOSIM between the species richness and abundance of the topsoil seed stores across the 12 mine sites was significant (overall Global R=0.21, P<0.001). This is expected due to the variances in soil types across the 12 mines sites chosen for this preliminary study. The ordination showed some clustering for depth of sample and was supported by the ANOSIM indicating a significant difference between the groupings of the depths (0-20 cm and 80-100 cm - overall Global R =0.112, P<0.001; Figure 4.15). This can be explained by the deterioration that seeds endure as a result of soil burial. The plant species were divided into native and non-native species (with unknowns removed), but did not group significantly in the ordination (Global R = 0.016, P=0.277).

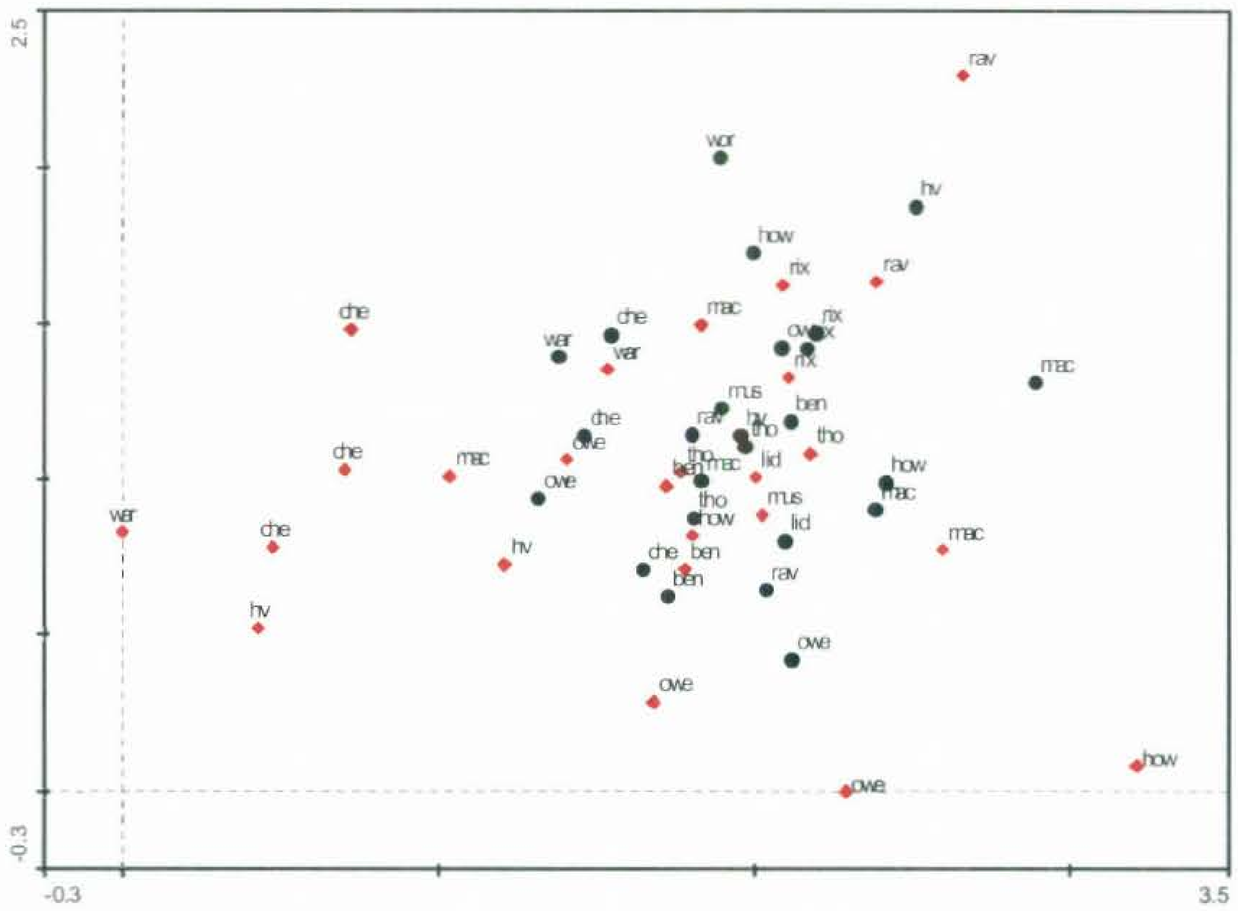

Figure 4.15: Ordination (DCA) of plant species indicating the depths samples were collected from 0-20 cm (black dot) and 80-100cm (red diamond). Codes relate to mine site name where the topsoil was collected where (ben = Bengalla, che = Cheshunt, how = Howick, hv = Hunter Valley no.1, lid = Liddell, mac = Mt Arthur Coal, mus = Muswellbrook, owe = Mt. Owen, rav = Ravensworth, rix = Rixs Creek, tho = Mt. Thorley, war = Warkworth).

4.4 CONCLUSIONS

When the Hunter Valley is compared to the Bowen Basin, differences in topsoil stockpile characteristics were evident. The Hunter Valley stockpiles were younger, taller but of lower volume than those in the Bowen Basin. Therefore, the Hunter Valley appears to be unique and results from previous studies from the Basin Bowen should not be applied to mines in the Hunter Valley. Thirteen of the 21 stockpile physical, chemical and biological parameters differed significantly across the 12 mine sites indicative of the variable soil types present in the Hunter Valley. Height and age of stockpiles did not significantly affect the majority of physical, chemical and biological characteristics investigated. However, of the 13 chemical parameters, exchangeable cations, available and total P and N exhibited significant relationships with height, age and depth of sampling. Nitrate-N, NH_4-N and exchangeable cations were significantly higher in the 80-100 cm compared to the 0-20 cm depth. This is probably indicative of leaching. Calcium and K increased with increasing height and age of stockpiles, while Na levels decreased. These patterns are indications of the effects of leaching and the displacement of cations on exchange sites. Available and total P showed a significant increase with age of stockpiles, as a result of the re-establishment of vegetation cover. The clay and silt fraction was greater at depth in older stockpiles, indicative of significant downward movement of fine material in stockpiles. Microbial respiration was positively correlated with vegetation cover and maximal in moderately aged stockpiles. Microbial respiration probably decreased in older stockpiles as the anaerobic zone becomes more extensive. The multivariate analysis of the topsoil seed stores species richness and seed density also emphasised the mine site differences and depth of sampling. This chapter emphasised the differences in soil types across mine sites in the Hunter Valley, the importance of leaching as a process for the re-distribution of nutrients through the stockpile profile and the contribution that the re-establishment of vegetation on the stockpile surface makes to soil quality.