CHAPTER 1

INTRODUCTION

1.1 A Perspective on Open-Cut Coal Mine Rehabilitation in the Hunter Valley

Rehabilitation of open-cut mine spoil has become an important consideration for government bodies, the general public and mining companies themselves. Rehabilitation of mined land is required by statute in New South Wales. Part VII of the Coal Mining Act (1973) contains provisions relating specifically to the protection of the environment.

The development of detailed environmental legislation has largely reflected public and, in turn, government concern that mined sites retain at least a pre-mining land capability, and that environmental degradation in the form of air and water pollution and the loss of aesthetic value be minimised. Under the authority of the Coal Mining Act, the Soil Conservation Service of New South Wales advises the State Department of Mineral Resources on rehabilitation requirements for mined land. The Soil Conservation Service of New South Wales (1985) has developed guidelines to meet requirements for information on soil and land stability in proposals for open-cut mining and rehabilitation.

To date, most open-cut mining has taken place on land previously used for grazing of sheep and cattle. In New South Wales and particularly in the Hunter Valley, rehabilitation has largely concentrated on minimizing the loss of agricultural and pastoral productivity and prevention of erosion and stream pollution. To this end, quick growing, hardy exotic pasture species have largely been used. In the process, the requirement of rapid surface stabilization has been met. While the use of exotic pasture species is understandable, Hannan (1981) suggests that this approach may not necessarily achieve a land use which is the most stable or productive for each particular site, or which is compatible with other surrounding land uses. He further stated that research and development of other land uses may more than pay for themselves in earlier completion of rehabilitation and the return of guarantee deposits and in lower management and maintenance costs.

1.2 History of Tree Planting on Spoil in the Hunter Valley

Prior to the 1970's, little consideration was given to rehabilitation of mined land and apart from several small tree plantations established by the N.S.W. Forestry Commission, no attempts were made at revegetation.

Changing community attitudes and the Coal Mining Act (1973) resulted in the first attempts at large scale rehabilitation of surface coal mines being undertaken in 1973. Most attempts to rehabilitate surface spoil dumps were for grazing purposes, the major emphasis being on contouring land to less than 10 degrees side slope, correct drainage and establishing a healthy grass sward to stabilize the surface and provide pasture for envisaged livestock.

Until the early 1980's tree planting played only a minor role in the revegetation of open-cut coal mines. Most open-cut mining in New South Wales has occurred in the Hunter Valley. Even as late as June, 1983, of the 715 hectares of mined land that had been revegetated in New South Wales (N.S.W. Coal Assoc. 1984) it has been estimated that less than two per cent of this area had been successfully planted with native trees.

It was not until the early 1980's that the use of native woody vegetation was seriously considered as a viable revegetation adjunct to exotic pasture establishment. The delay was undoubtedly influenced by a lack of research and extension advice and by several early failures of native tree species planted into dense pasture swards. The apparent inability of native tree and shrub species to provide rapid surface stabilization and a general uncertainty of the tolerance of native trees to broad physical and chemical spoil characteristics were undoubtedly other factors.

Since 1983, routine tree planting on varying scales has been regularly undertaken on a range of open-cut collieries in the upper Hunter Valley. Over 120 hectares of trees have since been planted on spoil in the Hunter Valley. These trees have been planted into a variety of overburden and topdressing materials. Despite obvious variations in growing media, where trees were kept free of grass or weeds in their establishment phase, and where deep ripping was employed, growth was generally good over a relatively wide range of sites and species tested.

Due to the initial biologically inert, weed-free nature of many of these materials, development of direct seeding techniques appeared a logical next step. This step was also prompted by a need for a cheaper technique to seedling planting, as well as a widely felt need to establish trees in a more random and natural arrangement, together with the hope that trees established from in-situ seed may be more adapted to the site.

1.3 General Factors Affecting the Nature and Suitability of Surface Material Used on Reformed Mine Sites for Revegetation

At each mine the spoil material presents different limitations to plant growth. These limitations may relate to plant adaptability, climate, or the physical and chemical limitations of spoil material which in turn may vary within the mine. While plant adaptability and climate responses are generally well documented the suitability of many spoil materials to support growth has generally not been examined. Coal mines present a unique opportunity to examine substrate material that has not seen the sun for 200 million years and which has been kept under pressure until released through mining.

In any open-cut coal mine profile the range of material is considerable. Mixing during overburden stripping and stockpiling presents a further dimension to the problem. On many mines pre-stripped surface soil horizons (topdressing material) have been traditionally respread on reshaped spoil dumps. However, insufficient quantities of good quality material are available for topdressing on most mine sites in the Hunter Valley. This problem and the alternative of utilizing spoil material as the surface for revegetation, has not been adequately studied in most revegetation investigations to date. As rehabilitation proceeds and disturbed areas become larger, the need to assess the potential of non-traditional surface materials has become more critical.

1.4 Aims of the Study

The aims of the study are:-

1.to compare the suitability of traditional topdressing material and a range of other spoil materials as substrates for revegetation with native trees.

2.to determine what physical and/or chemical substrate characteristics are important in the germination and early growth of native trees.

3.to develop a practical set of guidelines and recommendations for the large scale use of direct seeding of native trees on recontoured open-cut coal mine spoil within the Hunter Valley.

At the commencement of the study it was appreciated that within individual collieries wide variations in the characteristics of topsoil, overburden and interburden material could exist due to the variety of strata being mined and the mining method (e.g. truck and shovel or dragline) being used. Within this framework, the importance of identifying the specific limiting physical and chemical substrate parameters was recognised if extrapolation of results was to be practicable.

The study was not intended to examine all the open-cut sites available in the Hunter Valley, nor did it attempt to define all the likely physical and chemical substrate factors which may exist on any one site. Rather, research concentrated on examining likely physical and chemical limitations to the germination, early growth and survival of selected native tree species on a small number of contrasting spoils from different collieries. To this end, earlier research in the Hunter Valley and other coal-mining areas in Australia provided an initial focus on likely limiting factors.

Examination of the physical and chemical factors limiting establishment was undertaken using the general approach outlined by Bell and Whiteman (1975). This consisted of four steps:

(1) Analysis of the mine environment,

(2) Laboratory characterization of the properties of spoil material,

(3) Glasshouse assessment of germination and early growth on selected spoil material and

(4) Field trials at the mine sites.

The study was undertaken during the period 1985 to mid-1987 and represented the first large-scale systematic investigation of factors affecting native tree establishment on open-cut coal mines in the Hunter Valley.

1.5 Terminology

With the growing importance of rehabilitation has come a terminology which, unfortunately, is not yet uniform within the field. For the purpose of this study, terms used in the following sections are as defined.

Mine rehabilitation consists of three main phases, namely **site evaluation, recontouring** and **stabilization** of the recontoured landscape. Stabilization can be achieved by physical, chemical and vegetative means. Hence, revegetation used in this sense is a part of the rehabilitation process and not a type of rehabilitation.

All non-coal materials are similarly defined as **spoil** or **substrates.** Included in these classifications are all materials overlying or lying between coal mine seams and topdressing materials disturbed and replaced during the mining process. As such, it includes the former topsoil layers which, due to their method of stripping, storage and respreading, are sufficiently mixed such that they are better described as **topdressing** material. At most coal-mine sites within the Hunter Valley topdressing material is usually a mixture of the upper 15cm of soil which may include the A horizon where present and material from the lower or B and C horizons (Schafer 1979, Grundy and Bell 1981).

Within the classification of spoil or substrate three broad categories are generally discussed within the study. These include **topdressing, sandstone** and **shale** material and most coal mines have materials falling generally into these three categories. These classifications are simply based on the general lithological characteristics of the material. However, the characteristics of visually similar materials may vary considerably, both within and between collieries. For this reason, each substrate used is characterized in terms of its main physical and chemical characteristics in Chapter 4 and ascribed a reference number.

CHAPTER 2

REVIEW OF THE LITERATURE

2.1 The Rehabilitation Process

The aims of rehabilitation of mine spoils are manifold and include the reduction of wind and water erosion, reduced contamination of waterways and minimization of adverse aesthetic properties. The overriding objective is more abstract and is a return of land capability. i.e. to a capability, usually for agriculture, that existed prior to mining. With such a broad aim, a great deal of variation in approaches to rehabilitation exists world-wide. However, rehabilitation can usually be separated into three distinct phases, namely (i) site evaluation, (ii) recontouring and (iii) stabilization which includes revegetation.

2.1.1 Site Evaluation

For maximum benefit from rehabilitation efforts, investigation into the potential or desired land use after mining is essential. This should entail an assessment of both topdressing and other spoil material and particularly their suitability as surface materials. The varying quality and often limited availability of suitable topdressing material may necessitate an assessment of the potential of lower profile materials for surface use.

Spoil materials have been classified in many ways, the principal objective commonly being to reflect revegetation potential. For example, the Indiana Coal Producers' Association in the 1940's used chemical tests to classify spoils for reafforestation or pasture development (Sawyer 1946) and pH has been widely used as a basis for general spoil classification (Grandt and Lang 1958, Limstrom 1960). Many sub-divisions have been used in connection with pH to classify revegetation problems. Grandt and Lang (1958) used texture classes of the spoil; Hodder and Sindelar (1972) suggested salinity and sodicity for Montana coalfields and Plass (1974) recognized stoniness and steepness classes for West Virginian coalfields. These classifications strongly reinforce the point that detailed site evaluation of specific localities is an important aid to rehabilitation.

Evaluation of overburden strata, so as to provide an assessment of the potential limitations of the material, is more relevant if selective placement of these materials is possible. Selective placement may mean placement of overburden at depth to avoid acid, toxic or physically poor material (Hill and Grim 1975) or placement of layers with beneficial properties near the surface (Plass 1978). In Australia, the economics of layer separation and selective placement have generally prevented this procedure in coal mining operations, although West Germany has used it for some time (Doubleday 1974). Plass (1974) described a situation where a mine replaced topdressing with the selective placement of an overburden stratum high in phosphorus (P).

The assessment of soils for use in rehabilitation normally involves the mapping of soils using standard soil description systems such as Great Soil Groups (Stace *et al.* 1968). However, these systems do not necessarily emphasize soil properties of importance to topdressing (Thompson *et al* 1978, Elliott and Veness 1981).

Numerous agencies have developed criteria for assessing the quality and suitability of topsoil, subsoil or selected overburden for plant growth; however, no single set of guidelines has achieved wide acceptance. The New South Wales Soil Conservation Service has chosen the properties of structure, coherence, mottling, macrostructure, ped strength, texture, pH, salt, colour and cutans for topsoil selection (Elliott and Veness 1981). Broader guidelines to meet requirements for soil and land stability in the rehabilitation of open-cut mining were published by the Service in 1985. The National Cooperative Soil Survey (N.C.S.S.) Western Region in the United states devised a suitability rating based on texture class, consistence, salinity, pH, stoniness, available water, rock fragment percentage and saturation water percentage (Schafer 1979). In both cases, the intention was to assess dryland agricultural potential of the various materials if spread on the mine surface.

2.1.2 Recontouring

Recontouring has become an integral part of rehabilitation and the extent to which spoil is reworked depends on the mining method and the ultimate post-mining land use. Major influences, apart from economic constraints, are erosion, potential surface drainage control and aesthetic factors. Recontouring also includes the placement of topsoil or suitable overburden strata over the spoil to aid vegetative stabilization.

In economic terms, earthworks account for most of the costs in rehabilitation. Over ninety per cent of expenditure on rehabilitation of spoils is normally spent on recontouring (Kelly 1979). Whilst accounting for most of the money and energy spent on rehabilitation, recontouring is a comparatively simple engineering task, when compared with the more complex operation of stabilizing spoils.

2.1.3 Methods of Stabilizing Mine Wastes

Mine spoil can be stabilized by three basic methods, namely physical, chemical and vegetative methods or combinations of these.

Physical methods such as the application of stone mulches, organic residues or topsoil can be used to reduce wind and water erosion (Storey 1963). However, these materials often encourage stabilization through their enhanced effect on vegetation by favourably altering soil moisture or temperature, or by providing a greater reservoir of available nutrients (Clemens 1984, Russell 1977).

Chemical stabilization involves the application of chemicals to form an air-and-water-resistant crust (Dean and Havens 1971). While cost may be high and the effects short-lived, chemical methods may be used to provide sufficient short term surface stability to allow vegetative establishment or in situations where climate or toxicities prevent plant growth (Bell and Whiteman 1975).

The third and most important means of stabilizing mine wastes is through the use of vegetation.

2.2 Revegetation

Vegetation has been widely used in coal mine stabilization. It has the benefits of economy, effectiveness and aesthetics. Ideally it should be self-regenerating and lead to favourable successional development without the need for irrigation or special care. A wide variety of native and exotic species has been used in revegetation in Australia. Revegetation can occur naturally, through colonization by native trees, shrubs or ground cover including grass species, or by planting or sowing with exotic grasses and legumes, or with trees and shrubs. Of particular concern to this study is the establishment of trees.

2.2.1 Factors Affecting the Natural Colonization of Mine Sites by Trees.

There are six general factors considered important in plant establishment by natural colonization (Dexter 1967):

1. seed supply
2. species competition
3. seed bed type
4. moisture availability
5. seed predation by insects and damage to the seed or young plants by animals.
6. incidence of flooding and fire.

To these might be added temperature and nutrient availability. Factors affecting natural seed supply on coal mines include the relatively short dispersal distance of native tree seed (Jacobs 1955), together with the often elevated nature of spoil heaps caused by the bulking effect of replaced spoil relative to potential seed sources on undisturbed ground.

Colonization by native trees has little chance of success where weed and grass competition are severe, an effect attributed mainly to moisture competition. Hall (1985) stated that removal of grass and weed competition facilitates germination and growth of tree seedlings.

The rate of colonization, the spatial arrangement of trees and the subsequent successional change is dependent on the potential of the spoil to support plant growth and the availability of other components required for succession. Failure of natural colonization on mine spoil, even after many years, has been attributed to very low pH (Dean and Havers 1971), heavy metal toxicity and a variety of other chemical and physical effects (Emmerton 1983, Evans 1985). Failure has also been attributed to harsh climatic conditions and particularly, low rainfall (James 1966).

Mined sites are initially devoid of insects immediately after recontouring. Insect populations reinvade from surrounding areas and populations may increase over time (Majer 1983). The effect of damaging insects on trees and shrubs will be dependent on the extent of reinvasion of these pests.

Flooding is not normally encountered on elevated recontoured mine sites. Fire may be a problem depending on the level of accumulated combustible fuel and likely sources of ignition.

One or more of the above factors can frequently be unfavourable and thus natural colonization of spoil by native species is often erratic and slow.

2.2.2 Natural Colonization of Mined Areas Within the Hunter Valley

Reinvasion of tree and shrub species onto mine spoil heaps has been noted on abandoned coal mine sites in the Lower Hunter. Vigorous development of several forest species has been noted on 25-year-old acid spoil at Neath Open Cut and on Maitland Main Colliery near Cessnock. Natural seeding of these areas has been aided by the close proximity of large mature parent trees and the relatively low elevation of most spoil heaps.

In the upper Hunter Valley regeneration of *Eucalyptus crebra* has been noted on strongly acid overburden (pH 3.7) near Howick Mine. Regeneration of the exotic *Schinus areira* has been noted on adjacent alkaline spoil (pH 9.2), possibly from bird dispersal of seed.

More recently, seedlings of *Acacia saligna* and *Eucalyptus dawsonii* were noted adjacent to parent trees planted in 1969 on post war spoil heaps opposite Ravensworth Village. In addition, the planted indigenous species, *Casuarina luehmannii* and *Acacia salicina* were also propagating themselves from seed on the same site (Kennedy 1982).

Natural regeneration of *Angophora floribunda, Casuarina glauca, Eucalyptus crebra* and *Schinus areira* has also been observed on the peripheries of old workings in the Ravensworth area, leading to the conclusion that once there is a stocking of suitable seed trees, re-establishment will be a continuing process (Kennedy 1982).

2.2.3 The Use of Trees in Rehabilitation

On a world-wide basis, trees have always had a place in rehabilitation of coal mine spoil. Most of the early vegetative stabilization of coal mining spoil in the U.S.A. and England consisted of reafforestation due in part to the greater capacity of trees to tolerate poor chemical and physical conditions and in part to the good growth of trees on spoil. Many trees have grown well in coarse-textured spoils with less than 20% of the particles less than 2mm in size (Schessler and Droege 1965). Ashby and Kolar (1977) reported excellent growth of a variety of native North American species on strip coal mines in the United States after 30 years. They found that the growth rates of these species were often much better than would be expected on unmined land. Uninhibited root growth was shown to be a major factor in successful tree growth.

In Australia, trees have historically been more widely used in bauxite and sand mining, than in coal mine rehabilitation. This may relate to the nature of the pre-mining vegetation and potential after-use which frequently determines the type of revegetation undertaken. Many open-cut coal mines are located within poor quality grazing country, while bauxite mining and sand mining is generally located within existing native forest or heath areas. However, the extent and sequence of tree planting in rehabilitation is often limited by the need to comply with mining regulations or by the background of practitioners. Khonke (1950) proposed that, in extremely acid spoil, trees should not be planted until volunteer herbaceous species establish. He believed that the volunteer species would ameliorate conditions, thus allowing successful establishment of trees. Similarly, for long term erosion control, Lyle and Evans (1979) consider the planting of trees and shrubs should occur after the establishment of a grass/legume sward. Hall (1985) suggested that both approaches could lead to heavy mortality and poor growth of native trees due to competition. Others considered tree establishment inimical to stability (Le Roy and Keller 1972) and its use has been consequently discouraged.

2.2.4 Comparing Tree Establishment Techniques

On reformed mined sites woody species can be artificially established, either by planting seedlings or by directly applying seed. The latter method, although more subject to environmental variations than planting, has potential for re-establishing trees on a far greater scale, at a higher density and at considerably less unit cost, compared to seedlings (Lawson 1983, Lawrie 1983). Weatherly (1985) claimed growth rates of direct sown seedlings were better than those of comparable containerized trees, as the initial set-backs of pricking out and planting out of containerized trees are avoided. Direct seeding may also be suitable for steep slopes where other methods of tree establishment are not suitable and may also lead to a more pleasing lack of formality in plant cover (Clemens 1984).

2.2.5 Direct Seeding

Direct seeding of native tree species is currently being used on a large scale in Australia. Direct seeding is the major regeneration technique used in native eucalypt forests in Victoria to regenerate cut over forest areas; aerial and hand seeding were used on 5,269 ha in 1983/84 (Manderson 1985). The technique has also been a common farm tree establishment technique in Australia, particularly in the first half of this century, and Corbin (1923) successfully broadcast seed of various eucalypts onto ploughed and harrowed land at Kuipto, South Australia, as early as 1923. For reasons unknown, the technique fell into disfavour in the middle part of this century, and interest is only slowly re-emerging, partly in response to an awareness of the problems caused by past over-clearing.

Considerable research into directly applying native tree seed to mine spoil has been undertaken in Australia, e.g. Bell (1980), Wise *et al.* (1980), Middleton (1979), Connolly and Brook (1983), Day and Ludeke (1980), Koch (1980), Lawrie (1983), and the technique is being routinely used on several sites, e.g. Weipa (Lawrie 1983).

Several attempts have been made to establish trees from artificially applied seed on coal mine spoil within the Hunter Valley. In 1978 direct seeding trials were established at Ravensworth No. 2 and Howick Mine, using seed of both *Casuarina* and *Eucalyptus* species (Hannan 1981). The trial failed due to abnormally dry seasonal conditions which followed and also to competition from pasture grasses. In June 1981, the Soil Conservation Service established a direct seeding trial in conjunction with a tree planting trial on Ravensworth No. 2 colliery (Dyson 1985). Significant regeneration resulted on both topsoiled and overburden sites after three years. Good results were also obtained at Saxonvale Mine (Farnell 1983) and Hunter Valley No. 1 Mine (Agar 1984) on topdressed sites using a variety of techniques. Burns (1985) also obtained good establishment and growth on both topdressed and spoil material on a number of collieries, using simple application techniques.

Due to the small size of most native tree seed, particularly seed of *Eucalyptus* species, most success has been obtained by surface sowing (Grewar 1985, Manderson 1985, Venning *et al.* 1985). Raindrop impact shatters clods and causes splash; the splash covers seed with fine soil granules and sand grains. This is often adequate seed cover (Russell 1961). In this way, the process differs from agricultural practice.

Manderson (1985) considered the success of any seeding operation, whether it be in agriculture or mine spoil rehabilitation, depends on three key factors always being present: seed source (good quality seed), good seedbed preparation (including removal of competing species), and good seasonal conditions. The principles do not vary from those considered important to successful natural colonisation by trees discussed in Section 2.2.1. In mining operations, Hunter and Whiteman (1974) found that the general problems, other than climatic, can be defined in terms of physical and chemical soil limitations. Marshall (1983) considered that biological factors can also be important. Mined sites, generally, do not initially suffer severe insect (and particularly ant) predation of seed common to native forests due to a lag in the return of insects after mining (Majer 1983).

2.3 Establishment of Native Flora on Mined Land

In much of the literature on coal mine rehabilitation the period for which surface materials have been exposed to the atmosphere and the degree of weathering of the exposed materials are not stated. These aspects are important in terms of likely physical and chemical effects and their influence on plant establishment. Consequently, care must be taken in this regard in comparing research results and in further confounding past incorrect conclusions and comparisons.

2.3.1 The Effect of Mining on Overburden Strata

A characteristic of surface mining is the disturbance of the stratigraphic relationship of strata due to their removal and placement during mining.

Surface coal mining projects in the Hunter Valley are either dragline or truck and shovel operations. In either case, topsoil is normally stripped and stockpiled if necessary prior to the removal of overburden. At the beginning of an operation, the first overburden removed is usually emplaced adjacent to, but out of the pit. Subsequent workings abut overburden against this emplacement thereby backfilling previously mined areas. This method of mining normally results in the original stratigraphic sequence being inverted and mixed, and large quantities of unweathered, fragmented rock are exposed to the weathering process. This, together with grading and erosion, causes variability in coal mine spoil. The chemical and physical properties of spoils can be highly variable, not only between different spoils, but within individual spoil banks (Schessler and Droege 1965, Geyer and Rogers 1972, Grandt 1978). Russell (1978) found the range of nutrient supply and chemical conditions in spoil greater within each of four mines in Central Queensland than between mines. Extremes of chemical conditions may exist only centimetres apart on the spoil surface or within the plant rooting zone (Riley 1975).

In an intensive investigation of chemical characteristics of overburden from surface coal mines in the upper Hunter Valley, the State Pollution Control Commission (SPCC 1983) indicated that three chemical conditions may arise from overburden exposure and weathering and may result in restricted plant growth and environmental degradation. These include salinity, sodicity and pH extremes. In addition, Elliott and Hannan (1980) considered that nutritional deficiencies may also limit growth on some overburdens. Chemical soil problems found prior to mining may also re-establish themselves if those materials are stripped, stock-piled and respread. In unmined areas in the Muswellbrook District, Walker and Elliott (1982) have associated four chemotoxic problems associated with bare eroding areas. They include toxic concentrations of bicarbonate and chloride (Cl), an induced iron deficiency, and an unfavourable calcium (Ca) to magnesium (Mg) ratio. However, there has been no record of these toxicity problems reappearing on mine sites.

2.3.2 Differences in Soil Chemical Conditions Following Overburden Disturbance and Their Effect on Plant Growth

2.3.2.1 Salinity

High salinity levels have been recorded in overburden strata, and to a lesser extent topsoil material on coal mines in the Hunter Valley (SPCC 1983). At the mines of the Bowen Basin in Central Queensland salt is released from sedimentary rocks of marine origin which overlie the coal deposits. This salinity limits the growth of plants revegetating the replaced overburden (Bell 1982).

Soils in drier regions such as the upper Hunter Valley contain small amounts of salts in their surface horizons, and salt problems are mostly due to the movement of salt from deeper layers to the surface (SPCC 1983). However, there is a lack of data on plant responses to salt levels in lower overburden material, and this deficiency is even more pronounced for native species.

Extremely saline soils are usually bare of vegetation and have poor structure, low permeability, low fertility and low organic matter contents. They are very susceptible to water erosion.

Plants have differing levels of salt tolerance during different stages of growth (Nieman and Shannon 1976; Pasternak and Forti 1980). Bernstein and Hayward (1958) reported that many species were less physiologically susceptible to salt at germination than at later stages of growth. Cook (1983) showed that the tolerance of *E. maculata* at germination (19 mS cm^{-1}) was greater than that during growth (14 mS cm^{-1}). Under saline conditions the long term survival of vegetation depended as much on the tolerance of the germinating seeds as on the tolerance of the seedlings and adult plants (Morris 1980).

2.3.2.1.1 The Effects of Salinity on Germination

The effect of salinity on seed germination has received far less attention than the effect of salinity on plant growth. It is often only mentioned as a point of interest (Koller 1972).

Most major experiments to determine the effect of different levels of salts on germination have been carried out in solution culture (Younis and Hatata 1971, Ryan *et al.* 1975). Whereas a level of salinity limiting germination may be obtained in the laboratory this cannot be directly applied to a saturation extract of a field soil or spoil, as conditions are much more severe in the field. Ashby *et al.* (1979) stated, "drought markedly increases the effect of dissolved ions. As soil moisture is depleted by evaporation and transpiration, the concentration of dissolved ions becomes progressively greater, and some may even reach saturation. Roots thus may actually encounter concentrations of dissolved ions much more limiting than those measured using laboratory procedures." This will apply also for seeds. Seeds appear to be in a more disadvantaged position, however, as they germinate in the surface few centimetres of the soil, which tends to dry extremely rapidly. It is also recognised that in saline areas where salinity extends to the surface, a higher concentration of salts exist at the surface in the form of a salt crust (Teakle 1937, Evans 1967).

Salinity affects germination through two processes (Ayers and Hayward 1948), namely:-

(1) the decrease in ease of water uptake and

(2) the uptake of ions to toxic levels.

Young seedlings respond to these effects through a reduction in the rate or vigour of germination and a reduction in the final germination percentage (Bernstein and Hayward 1958). The delay in germination is possibly a result of the osmotic restrictions on water uptake while the reduction in germination percentage may be due to specific ion toxicity (Ayers 1952).

The effect of osmotic stress on germination of eucalypts has been investigated using solutions of mannitol. Edgar (1977) found a 50% reduction in germination rate of *E. camaldulensis* at an osmotic pressure of -4 bars and very little germination occurred at -10 bars (equivalent to E.C. values of NaCl solutions of approximately 14 mS cm^{-1} and 35 mS cm^{-1} respectively). *E. regnans* showed no significant reduction in germination at -6 bars (approximately 21 mS cm^{-1} NaCl), while only 25% of the maximum germination occurred at -8 bars (approximately 27 mS cm^{-1} NaCl). Zohar *et al.* (1975) found a 50% reduction in germination of *E. occidentalis* at an osmotic pressure of -9.1 bars (approximately 31 mS cm^{-1} NaCl).

The effect in these experiments was due solely to osmotic stress and confirms the findings of Okamoto *et al.* (1975) who found that the relative germination rate of a range of grass species decreased markedly with increase in osmotic potential. Specific ion toxicities could be expected to lower tolerance further.

Beadle (1952) reported that seed of the same species from different areas may vary markedly in salt tolerance and is dependent on the salt level of the environment of the parent plants. Sands (1981) found that seed of *E. camaldulensis* from a low salt site suffered greater reduction in germination percentage due to salt than seed from high salt areas.

2.3.2.1.2 The Effects of Salinity on Plant Growth

There has been little research into the effects of salinity on native plant growth. Some halophytes can grow on soils of up to 20% (312 mS cm^{-1}) salt content, although most grow on soils of 2% (31 mS cm^{-1}) to 6% (93 mS cm^{-1})(Strogonov 1964). Many plants can survive salinities greater than 20 mS cm^{-1}. The replaced overburdens of Central Queensland mines often have electrical conductivity (E.C.) values of 4 to 10 mS cm^{-1}, while the salinity of tailings from refinery operations often exceeds 20 mS cm^{-1} (Bell 1982).

Variations amongst species in relation to salt tolerance are given by many authors (e.g. Jenkin 1980, Parsons 1968 and Russell 1976). Parsons' (1968) findings suggest that variations in salt tolerance between two species of mallee (*E. incrassata* and *E. diversifolia*) are more important in determining their distribution than variations in their tolerance to water-logging.

Large variations in salt tolerance can occur within a species. This is particularly so with a widespread species occupying a broad range of environmental conditions. *E. camaldulensis* is very widespread throughout Australia and shows wide variability in salt tolerance (Ralph 1981). The more salt tolerant strains have been selected for salt land rehabilitation in Victoria.

The salt tolerance of an individual plant decreases with any additional stress. Elevated temperatures, high light intensities and low atmospheric humidity increase the transpiration rate and reduce salt tolerance (Morris 1980). It is likely that the reduction in tolerance under these conditions is due to osmotic restrictions on water uptake, similar to those shown by Edgar (1977) for germination. In mallee areas of Victoria, Matheson (1968) observed drought symptoms on trees even when the soil was wet. Pot experiments exposing *E. diversifolia*, a species from low salt areas, to increasing salt levels found stress symptoms due to water stress as well as Cl toxicity (Parsons 1968).

While salinity may be a limiting factor in growth, plants still respond to other influences such as nutrition. Ravikovitch and Porath (1967) found that, in general, the crop response to various fertilizer formulas on saline soils reflected the response to the same formula in nonsaline soils. They did, however, find that P was particularly important in promoting maximum yield on saline soils and that there was a trend towards decreasing P uptake with increasing salinity.

Youngner and Lunt (1967), working with couch grass, found that root to shoot ratios increased with increasing salinity. They considered that physiological stress from salinity was similar to that from increasing water tension and some grass species may have developed an adaptive response which maintained root growth at the expense of shoot growth as water or salinity stress developed.

Knowledge of the salt tolerance of eucalypts is often based on subjective and qualitative field data. *E. tereticornis* has been reported to suffer salinity induced dieback in many parts of south-east and Central Queensland (Wylie and Bevege 1981). Pasternak and Forti (1980) reported a method of assessing field tolerance through irrigation of eucalypt species stands with water of varying salinities. Wide variability was found using this method possibly due to lack of controlled conditions as well as genetic variability. Subjective field observations appear to be the basis for compiling lists of salt tolerant species as given by Matheson (1968) and most Forestry Departments.

Salts are rarely uniformly distributed in the soil profile and are often higher at the surface due to evaporative concentration (Smith and Stoneman 1970). Mature plants may be able to avoid high concentrations found in some horizons.

The use of trees is seen by some researchers, e.g. Cook (1983), as the main treatment needed to stop saline deterioration and off-site environmental problems. In the Hunter Valley, the planting of a vigorous vegetation cover, including deep-rooted species such as trees, has been proposed for rehabilitated coal mine sites in order to utilize moisture which might otherwise penetrate through spoil heaps and mobilize soluble salts (SPCC 1983).

Salinity is not a major factor limiting plant establishment on Hunter Valley collieries and only 16 per cent of overburden samples from the Wittingham Coal Measures and one per cent of topsoils sampled had a salinity which could adversely affect the growth of some crop species (SPCC 1983). No particular formation was identified which was consistently highly saline at all sites surveyed.

2.3.2.2 The Effects of Sodicity on Plant Establishment

Sodicity refers to a condition where a relatively high proportion of readily soluble sodium (Na) is present in soil or spoil material. The effects of sodicity on plant establishment have been widely studied in the case of agricultural soils, but very little information is available in the case of mine spoils where active weathering of exposed rock can result in rapid changes in ionic conditions of the substrate.

The ratio of Na to divalent cations, the Sodium Adsorption Ratio (SAR), in saturation extracts is frequently used as an index of sodicity (Richards 1954). The exchangeable Na percentage (ESP) gives a measure of the proportion of Na adsorbed on the exchange complex. Factors which relate SAR to ESP have been determined empirically for agricultural soils (Richards 1954), but Jurinak *et al.* (1981) have shown that the factors are different for coal mine spoil, although an approximate numerical equivalence is likely.

The SAR's of saturated extracts have been used as an indication of potential for Na toxicity in plants. While there has been a paucity of research into the tolerance of native species to Na, levels have been established for many commercial crops. The Na tolerance of some commercial crop species as related to the ESP of soils or SAR of irrigation water is shown in Table 2.1.

The State Pollution Control Commission (SPCC 1983) considered SAR values of coal mine topsoils with values less than 5 favourable for

Table 2.1 Tolerance of crops to exchangeable sodium percentage (ESP) of soils or sodium absorption ratio (SAR) of irrigation water.

Tolerance	ESP	SAR	Crop
Extremely Sensitive	2-10	2-8.5	Deciduous fruits Nuts Citrus Avocado
Sensitive	10-20	8.5-18	Beans
Moderately Tolerant	20-40	18-46	Clover Oats Tall fescue Rice Dallas grass
Tolerant	40-60	46-102	Wheat Cotton Lucerne Barley Tomatoes Rhodes grass

Sources : Allison (1968) and Chatfield (1967). cited in Hart (1974).

maintaining soil structure and for avoiding Na toxicity problems; SAR values between 5 and 15 were considered more likely to be unfavourable.

In addition to direct toxic effects, unfavourable Na levels can indirectly affect plant establishment through their effect on surface structure and erodibility. Russell (1980) noted that a high exchangeable sodium percentage (ESP) can affect the physical nature of spoil material and is one of the important factors affecting the tendency of soils to disperse. As the percentage of Na on the exchange complex increases, the tendency for the clay to disperse increases, resulting in soil surface crusting, reduced infiltration and consequent reduced plant growth, high run-off and erosion.

High surface run-off and erosion can lead to the loss of plant material and, particularly, seed from site, or the burial of seed to a depth below which it cannot emerge. Cremer (1965) found that most eucalypt seed-germination is inhibited by burial greater than 5 mm.

Erosion can also result in the loss of plant nutrients (Schessler and Droege 1965) and exposure of 'fresh' spoil with its potential for chemical and physical problems (Anderson and Briggs 1979).

However, the effect of sodicity on plant establishment should be kept in perspective. Seedsman and Emerson (1981), in studies on the dispersion characteristics of Permian overburden in Central Queensland, indicated that mechanical disruption (e.g. by tractors and scrapers) of moist overburden particles is of greater importance in affecting subsequent dispersion than very high ESP levels.

The potential problems relating to revegetation of spoil from the Wittingham Coal Measures in the upper Hunter Valley mainly relate to surface sealing, poor moisture penetration and erosion which, in turn, commonly relate to an unfavourable ESP. The State Pollution Control Commission (1983) noted that while sodicity varied markedly from site to site, at least 67 per cent of Wittingham overburden samples had poor sodic properties. None of the topdressing materials was considered to have unfavourable SARs (greater than 5:1).

2.3.2.3 The Effects of pH on Plant Establishment

Both acidity and alkalinity can be limiting factors to successful plant establishment. Acidity of spoil has been considered by many authors to be the most important variable determining the success of revegetation (Byrnes and Miller 1973, Smith *et al.* 1971, Tasker and Chadwick 1978, and Plass 1974).

However, conditions for plant growth can be difficult when waste is extremely alkaline, both because of high pH and the decreasing availability of plant nutrients (Bell 1981). Many plants suffer from phosphate deficiency if the pH rises much above 8 (Russell 1978), while immobilization of micronutrients, including zinc, copper and manganese, can restrict plant growth (Mortvedt *et al.* 1972). Handreck and Black (1984) considered that the effect of pH on nutrient availability is particularly important when the supply of nutrients is poor. However, if nutrients are continuously supplied in adequate amounts the effect of pH is far less important. High hydroxyl ion concentrations have a direct detrimental effect on plants particularly at a pH of 10.5 and above (Olsen 1953) while high pH in heavy metal mine slimes has been noted to give rise to boron deficiency in *Eucalyptus* (Fox 1984).

Acid overburden is not common in the Wittingham Coal Measures. In the Greta Coal Measures, acid overburden is common where the potential exists for both the development of acidic leachate and the inhibition of plant growth by acidic surface spoil.

In the area surveyed by the State Pollution Control Commission the pH of soil types varies from 6.5 to 8.0 for solonetz, 4.8 to 6.8 for solodized solonetz and solodics and 5.3 to 6.3 for podzolic soils (Stace *et al.* 1968). The pH values of Wittingham bedrock and unconsolidated bedrock were grouped around the median value of pH 8.6, the range being from 4.3 to

9.6, with 10 per cent of samples lying outside the acceptable agricultural range of 5 to 9, and thus potentially posing environmental problems previously discussed.

2.3.2.4 The Effect of Nutrient Deficiency on Plant Establishment

Spoils are usually deficient in many of the essential nutrients. It has been almost impossible to establish a plant cover on wastes without adding fertilizers (Hunter and Whiteman 1974), especially P and nitrogen (N). These have been the major deficient nutrients on coal mine spoil in the Hunter Valley (Hannan 1979b). Low potassium (K) levels have been reported by Geyer and Rogers (1972) in the United States and Hannan (1979a) in the Hunter Valley. Barnhisel and Massey (1969) reported low Ca and K levels on Kentucky coal spoil. Rarely are other macronutrients deficient in coal mine spoil (Fitter and Bradshaw 1974, Plass 1978).

Micronutrient deficiencies have been reported, but no one micronutrient can be said to be commonly deficient. Low copper levels have been reported by Riley (1975) in the U.S.A. and Hannan (1978) in the Hunter Valley. Low levels of molybdenum and boron were documented by Hannan (1978) for coal mines in the Hunter Valley. These low levels were reported on the basis of chemical analysis, but it should be noted that field growth deficiencies were rarely detected in these cases.

Spoil materials are frequently devoid of biological activity immediately following mining. There are essentially no bacteria and fungi (Jehne and Bowen 1981, Langkamp 1981) or animals (Majer 1983) to break down any introduced organic matter. Consequently, the low initial nutrient status of most spoil material following mining is exacerbated by its inability to build up mineral nutrient levels through organic decomposition (Marshall 1983).

Soils overlying unmined coal deposits can also lack important elements and are traditionally low in major nutrients (Hannan 1976, Irving 1986). The problem of nutrient deficiency is further complicated by the common occurrence of variations in the type and degree of deficiency for different layers of the subsoil profile as, for example, at Gregory (Evans *et al.* 1979) and at Saraji (Carter 1981), coal mines in Queensland.

Ward (1983) showed that lack of N and P are the main factors which can limit *Eucalyptus* tree growth on recontoured bauxite mine sites. Reynolds (1983) showed an excellent response by a variety of trees and, particularly eucalypt species, to a broadcast application of 400 kg ha^{-1} of 18(N) : 18(P) : 0(K) fertilizer at Ravensworth No. 2 Colliery in the upper Hunter Valley. Irving (1986) showed a significant growth response by native trees to both applied N and P in a range of coal mine overburden materials, including topsoil. He also demonstrated a significant N by P interaction and showed that high levels of both N and P produced a synergistic increase in growth. Richards (1961) showed that the N/P balance which had a marked influence on the biomass of *Pinus taeda* seedlings, did not affect germination or seedling survival.

The possibility of strong interactions between N and P can be expected in field trials, and Bevege (1983) showed a significant interaction effect for several eucalypt species on oxidized and sandstone overburden at Callide in Queensland. However, interactions between these two major nutrients have been rarely examined for spoil materials and for most native tree species.

If germination is regarded in the purely physiological sense of resumption of active growth by the embryo, it is doubtful if this could be affected by nutrients (Brown and Johnston 1980, Hunter and Whiteman 1974), nor nutrient imbalance (Richards 1961).

Phosphorus

Lawson (1983) found *eucalyptus* emergence was highest when P was applied alone, and P seemed essential for initial seedling establishment (Christensen 1974).

Phosphorus is essential for initial root development, thus ensuring a greater likelihood of survival under moisture and nutrient stress (Lawson 1983). The enhanced effect of P on emergence may well be a result of more rapid radicle development resulting in faster hypocotyl development and higher seedling field germination capacity.

Bell (1985) showed a growth response by small seeded eucalypts to applied P. He considered that the lack of response by large seed size acacia and eucalypt species to P related to the fact that the large seed was able to supply most of the P requirements of the emerging plant. The effect of seed P reserves on the early growth response of Australian native species has also been documented by Barrow (1977) and Dell *et al.* (1983). Barrow (1977) observed that the time when the P response appeared in tree seedlings was affected by seed reserves. The larger the seed, the greater the P reserve, the more delayed the response.

While applied P has been noted to increase shoot growth in developing plants, the main effect is in increasing both root weight and the number of fine feeder roots (Dell *et al.* 1983). Consequently, it is not surprising that the application of P in the absence of N has been reported by some researchers e.g. Bevege (1983), to increase the root to shoot weight ratio.

Some spoil materials have adequate P (Barnhesil and Massey 1969, Grandt and Lang 1958, Plass 1974 and Geyer and Rogers 1972). Khonke (1950) documented cases where P levels of the spoil were higher than surrounding soils. Often adequate P levels are associated with specific overburden layers high in P (Plass 1974), although overburden is more often P deficient than not.

Applied P can be readily fixed by clay minerals and various metallic oxides and oxy-hydroxides in both low and high pH soils, thus reducing plant availability (Gemmell 1977, Fitter 1974). Natural vegetation development has been shown to be strongly retarded in alkaline wastes, where there is extreme phosphate fixation (Bradshaw 1983). Elliott (1981), using alkaline overburden and topdressing materials from upper

Hunter Valley mines, showed a fairly rapid conversion of soluble compounds of P to less soluble forms. The depth of movement of P following surface application can be quite shallow in coal mine spoil material and Elliott (1983b) showed in laboratory leaching studies that applied fertilizers were rapidly fixed and do not leach below 4 - 5 centimetres. This effect has also been noted in forest soils. Humphreys (1964) found there had been little loss of P from a forest site near Moss Vale 34 years after application. He noted no significant downward P movement deeper into the soil profile for either rock P or superphosphate. This is corroborated by the findings of Gilmore (1982) who reported little vertical movement of rock phosphate over 60 years with application rates in excess of 400 kg P ha^{-1} on soils supporting loblolly, shortleaf and red pines. Consequently, Elliott (1981) considered that although wetting fronts in spoil move about 17 mm per mm of rain, nutrients, particularly P, will never move out of the available root zone due to the high rate of surface fixation. While much of the applied P may still be in the root zone of shallow-rooted pasture species, it is possible a large proportion of the deeper roots of a well established tree may not have access to applied nutrients fixed in the surface layers. The extent of near-surface root development will determine access to nutrients in the surface layer. This effect could be further exacerbated by surface drying which may reduce root exploitation of the applied P and thus give a lower yield potential compared with that which might be obtained if the P fertilizer was mixed throughout the profile (Bell 1985), or placed at depth.

The excellent growth of native tree species planted on raw overburden material in the Hunter Valley (Dyson 1985, Connolly 1984, Burns 1985) suggested that adequate levels of nutrients were available to the plants at least for establishment. Koch (1985) considered that fixed P was not permanently lost but provided a slowly available supply. Mulette *et al.* (1974) showed that *Eucalyptus gummifera* exhibited a marked response to insoluble phosphates ($AlPO_4$, $FePO_4$). They presented an hypothesis for the mechanisms of P nutrition involving the interaction of root exudates, micro-organisms, aluminium ions and uptake mechanisms, and explained the response as an adaptive process evolved by plants growing on weathered and highly leached soils low in P.

Some topdressing materials used on coal mines have also shown a similar capability to absorb high levels of applied P (Elliott and Reynolds 1981). However, this effect may be partially balanced by the tendency of stripped and stockpiled topsoil to show an increase in extractable P levels and possibly in total mineral N (Elliott and Veness 1985).

Nitrogen

Bradshaw (1983) considered the predominant nutrient required for production in the majority of ecosystems is N, and that plant failure is frequently due to a shortage of N. Nitrogen deficiency has been identified as a major limiting factor in the growth of plants on spoils produced from the extraction of minerals (Davison and Jefferies 1966, Bradshaw and Chadwick 1980, Jefferies *et al.* 1981).

Koch (1985) showed a strong plant growth response to N on bauxite mines which lasted for three years and was evident in tree height, diameter, canopy density and foliar colour and nutrient levels. Lawson (1983) showed a height response by *E. maculata* seedlings to the application of N to topdressing material from Saxonvale Mine in the Hunter Valley.

Opinion on the effect of N on germination is divided largely due to the different reaction of plants to the various forms of N. Both Brown and Johnston (1980) and Hunter and Whiteman (1974) considered that enhanced nutrition rarely affects germination. However, Lawson (1983) found N in urea form to have the opposite effect to P, and to be detrimental to the germination of *E. maculata*. This is in agreement with work of Christensen (1974) in which quick-acting nitrogenous fertilizer in urea form caused early mortality of newly emerged karri (*E. diversicolor* F. Muell) seedlings in Western Australia. Pulsford (1981) attributed damage of several eucalypt species to volatilization of ammonia from applied urea. Fertilizers containing ammonium salts (urea) can alkalize adjacent soil through ureaolysis (hydrolysis of urea)(Handreck and Black, 1984). This effect is distinct from direct toxicity effects due to high concentrations of ammonium or nitrate salts. Richards and From (1965) considered that mortality in *P. taeda* was related to soil nitrate levels and showed that, as the soil nitrate level rose, germination was reduced and seedling mortality increased. As Ting (1945) had earlier reported, this effect was probably due to biological factors and particularly the promotion of damping-off by the soil pathogen *Fusarium* partly through increased growth of the pathogen and partly through increased susceptibility of the host. This effect could be expected to be more pronounced in topdressing material than in relatively biologically inert unweathered lower strata.

The preponderance of evidence from studies of the effect of N on plant growth suggests that the effect of N on root growth is quite small compared with its effect on top growth (Troughton 1957, Viets 1965, Wellbank *et al.* 1974, Nye and Tinker 1977). Roots show a limited growth response to N and even restricted root systems can absorb the highly mobile nitrate ion very efficiently (Burns 1980). It could therefore be expected that N applied in isolation has the ability to affect the root to shoot ratio and this, in turn, may affect plant resistance to water stress. For example, Campbell and Paul (1978) observed that when water is limiting, the addition of N can result in earlier water depletion, probably due to a greater leaf area and lower utilization of soil derived N. Increased moisture stress has also been recorded in nutritionally deficient plants growing in spoil (Fitter and Bradshaw 1974). This effect probably relates to a smaller root system as a result of inadequate available soil P and a consequent reduced ability to take up water. Bradshaw (1983) suggested that even in soil with very low available water capacity, drought could be relieved by supply of nutrients, particularly P. These results suggested the importance of a nutrient balance in efficient plant water usage.

The form of N supplied to seedlings influences growth rate and N uptake in *Eucalyptus* species (Moore and Keraitis 1971) while the ratio of N to P is also important and high levels of either in isolation can be detrimental (Groves and Keraitis 1976).

Nitrogen is not normally a constituent of soil minerals. Unlike P it does not derive from the weathering of soil materials and unless added artificially available N can only increase by biological fixation (Bradshaw 1983), atmospheric accession (Denmington and Chadwick 1978), or by mineralization of soil organic material. Yamanaka and Hall (1984) further suggested that soil P can increase in response to acidification in alkaline spoil as a result of increased ammonium levels.

While a single fertilizer dressing will usually provide enough N for a year's plant growth, it will not provide enough N for subsequent years, which must be supplied by further addition or through mineralization of soil organic matter (Handley and Bradshaw 1982).

Mineralization of soil N can be expected to be most apparent in topdressing material with an initial higher organic content. Elliott and Veness (1985) noted a possible increase in total mineral N after topsoil stripping and subsequent stockpiling. Irving (1986) suggested that soil N mineralized after topsoil disturbance is adequate for Rhodes grass during the first year of growth. However, the form of N affects its availability and McGinnies and Crofts (1986) showed that much of the N in coal mine spoil material may be unavailable for plant growth in the short term being bound in carbonaceous fragments. Due to the low N availability in these materials Dancer *et al.* (1977) suggested that N fixing plant species may have an advantage in colonizing spoils low in available N.

Despite the common deficiency of N in spoil Fitter and Bradshaw (1974) found N levels adequate for the growth of *Lolium perenne* in strongly acid shales and Coaldrake and Russell (1978) found variable field responses to N in the Bowen Coal Basin. Small reserves of N were available to plants on shale spoils, presumably resulting from the very slow degradation of carbonaceous material and perhaps also, in very small quantities from the clay minerals (Doubleday 1974). Coaldrake and Russell (1978) suggested that residual N from blasting with ammonium nitrate may add significant quantities of N to coal mine spoil. Power *et al.* (1978) detected moderate ammonium levels in blasted spoil but suggested that this was readily nitrified and subsequently leached. However, Reeder and Berg (1977) demonstrated slow rates of nitrification in spoil due to the absence of appropriate micro-organisms.

Fertilizers containing N are readily soluble in water and are, therefore, subject to leaching (Russell 1961, Bell 1985). Dancer (1975) stated that on raw china clay wastes (kaolin), 98 per cent of N fertilizer in nitrate form could be quickly leached beyond the rooting zone. Nitrogen (as ammonium) can also be made unavailable through colloidal adsorption. Elliott (1982) noted N adsorption in Hunter Valley coal spoil and showed that N in ammonium form did not appear to move as far as P in laboratory leaching column experiments.

2.3.2.5 Amelioration of Chemical Limitations

The salinity of spoil is usually a short term problem in humid climates and may disappear after two or three years of leaching. In drier climates the process takes longer and the problem may never disappear. Salinity can prove a limitation to plant growth where spoil has been recently recontoured and revegetated immediately (Doubleday 1974) and where leaching rains are low and water infiltration and internal drainage is poor.

Leaching of soluble salts has been noted on alkaline overburden of the Wittingham seam (Dyson 1987). Elliott (1983b) showed that the distribution of dominant water-soluble ions in the overburden appeared to be related to the occurrence of flood rains and there was a consistent accumulation of Na, Mg and Cl at 2.5 - 3 m below the material surface in overburden exposed for over 8 years. Leaching by irrigation can be used to reduce salt levels but this is rarely practical. As salt levels are rarely too high to prevent any plant growth the use of salt-tolerant plant species can be employed to overcome this problem. Salinity and indeed, all chemical problems can be partly overcome by selective placement of a favourable growing medium on the surface. However, as the roots of most plants and particularly deep rooting tree species will eventually penetrate the underlying spoil, the long-term success of revegetation work will depend on the quality of the underlying materials and adaption characteristics of species selected. Care must be taken to ensure that the selective placement of topdressing material does not slow down beneficial processes such as salt leaching in lower strata.

Sodicity may also be alleviated by leaching of Na salts over time. The ratio of Na ions to Ca or Mg ions can also be artificially varied by applying chemical additives to change this ratio. However, this is not always practical. Topdressing material in the upper Hunter Valley generally has favourable sodic properties (SPCC 1983) and is often used to cover overburden material with poor sodic properties.

Most methods of improving the pH status of spoil for plant growth have been developed for acid spoil (Miller *et al.* 1979). However, they can also be effectively applied to strongly alkaline spoil. Techniques include leaching, revegetation with tolerant plants, acidifying and liming and burial beneath soil or selected overburden strata.

Although most coal mine spoil is commonly deficient in at least one essential nutrient for plant growth, nutrient deficiencies are not considered a major problem in rehabilitation. Chemical soil tests developed for the prediction of nutrient availability in soils can provide a rapid assessment of the nutrient status of spoil and deficiencies can then be overcome by fertilizer application. However, where the specific fertilizer requirements of species are not known, as is the case for many native species; pot and field experiments are an important prelude in assessing nutrient deficiencies and appropriate application rates. Analytical methods, useful for assessing chemical and physical properties of spoils including nutritional characteristics, have been summarized by Sandoval and Power (1978), Schroer (1976), Amons and Perry (1979) and Schafer (1979) in the U.S.A. and Bell (1981) for Queensland.

Nutrient accumulation in the plant biomass and in spoil can be a slow process. Hannan (1979b) suggested that pasture crops may require fertilizer additions for up to five years.

In order to overcome fixation and leaching problems various slow release fertilizers such as IBDU (isobutadiene di-urea) and rock phosphate have been used to regulate the supply of nutrients to plants. However, their effect on growth has frequently been inconclusive (Koch 1985). Considerable work has recently been undertaken into the use of wide variety of seed coatings and seed pellet formulations (Beswick and Moran 1985, Venning et al. 1985, Sharp 1985). While some researchers have reported outstanding success (Weatherly 1985), others have shown no appreciable benefit (Beswick and Moran 1985, Grewar 1985).

In conclusion, the relative importance of chemical factors influencing revegetation varies from site to site. In the upper Hunter Valley the potential problems relating to mining of the Greta Coal Measures are different from those applying for the Wittingham Coal Measures. Salinity and saline drainage of spoil heaps are seen as the greatest problem with Greta Coal Measures, while surface sealing, poor moisture penetration and erosion, effects often related to unfavourable sodic properties, are the more intractable problems associated with overburden from the Wittingham Coal Measures. Nutrient deficiencies are common on all sites but can be identified and overcome.

2.3.3. Differences in Soil Physical Conditions Following Overburden Disturbance and Their Effect on Plant Establishment

Although the term 'soil physical conditions' is a subjective one which cannot be defined exactly, there are three distinguishing features of great importance. These are the particle size distribution of the solid mineral material which largely determines texture; the spatial arrangement of the pore space or soil structure, and the volumetric contents of solid, water and air. The soil's suitability as an environment for root growth and function depends on the availability of water, nutrients and oxygen, on temperature and on the degree of mechanical impedance to root extension (Eavis and Payne 1968)›

The physical nature of spoil can be inimical to plant growth. Materials may be unduly compacted, or loose and exposed to movement. Segregation of particle sizes will result in gradation of conditions with fine material prone to surface compaction and coarse material with little ability to hold moisture. The unnatural assemblage of materials often renders spoils liable to wind or water erosion. Extremes of moisture and temperature may be more severe than at undisturbed locations (Fox 1984).

Physical and chemical problems cannot be viewed in isolation. Physical problems such as surface crusting may have chemically induced origins e.g. sodicity (Emmerton 1983). Other physical problems can sometimes be ameliorated by chemical treatments such as augmenting nutrient supply (Fox 1984). Conversely, nutrient availability is often related to the physical properties of a soil (Bachelard 1985).

Generally, physical changes in spoil have received far less attention than chemical characteristics. With the exception of several limited water-relation studies by the Soil Conservation Service of N.S.W., e.g. Elliott (1983a), there have been few studies on the effects that physical changes may have on plant growth on coal mine spoil within the Hunter Valley.

2.3.3.1 Compaction

Soil compaction, as measured by bulk density, can be altered considerably during the rehabilitation of mineral workings, being either reduced when the material is deposited by face shovel and dragline or, more usually, increased when heavy box-scrapers and bulldozers are used (Doubleday 1974, Pederson *et al.* 1980). The bulk density of dry loam surface soil is about 1.3 g cm^{-3}. Bulk densities below 0.8 g cm^{-3} can lead to excessive drainage and limited water storage because of the high proportion of large pores (Swain 1983). Heavy-wheeled box-scrapers can exert a pressure on soil of 2 - 3 kg cm^{-2} (Downing 1977), and compactions of the order of 25 per cent on colliery shales have been reported, while 15 per cent was normal (University of Newcastle-upon-Tyne 1971). Shearing of high clay content soils can occur at the blade of the earth-mover. Even tracked vehicles cause disruption of the soil structure due to track slip when turning, uneven weight distribution when loaded, and engine vibration (Soane *et al.* 1977). Bulk densities approaching 2.0 g cm^{-3} have been reported (Marshall and Holmes 1979).

Soil compaction has the effect of reducing the proportion of large pores, and increasing the proportion of small pores due to the rearrangement of soil particles. As a result, the rate of water and gas movement into and through the profile is reduced (Swain 1983), root growth is impaired and rooting depth reduced (Rimmer 1979). Water stored in the soil is held more tightly because of the higher capillary forces present in the narrower pores, and less is thus available to the plants because of the higher resultant wilting point.

Smith *et al.*(1971) associated high bulk densities with a high percentage of rock fragments in the spoil; rock fragments in spoil are less weathered and porous than those in soil, and the structure of fines is absent or weakly developed in spoil. However, a high rock component is often associated with a large proportion of trapped air pockets, and this has been observed by the author in spoil profiles in the Hunter Valley. Care must be taken in drawing conclusions on likely plant growth effects from surface bulk density readings.

Russell (1978) showed that root growth is restricted in soils with a bulk density higher than 1.6 g cm^{-3}. As subsequent plant growth is often strongly related to root penetration (Burrows *et al.* 1981) reduction of the effect of compaction is important after mining (Burrows 1983). This particularly applies to new germinants (Pearce 1986).

2.3.3.2 Structural Instability and Texture

Spoil material consists of unconsolidated fragments varying from clay particles through to rocks and large boulders. Because of the lack of organic matter and/or biological activity in most spoil, few water-stable aggregates exist. As a result, porosity may not be favourable for root penetration and development, water infiltration and aeration (Martinick 1976). Ayerst (1978) suggested that on weathering, the fine-grained rocks release clay particles which seal pores of less-weathered material. Spoil texture problems thus vary depending on the amount of shales and mudstones, argillaceous sandstone and hard rock fragments present (Evans 1985).

2.3.3.3 Water Relations

Elliott (1986) demonstrated large differences between unmined soils in their capacity to support tree growth and related this to differences in available soil moisture. He showed this factor to be important in determining natural distribution of dry sclerophyll species in the upper Hunter Valley.

Hannan (1979b) stated that moisture availability is the greatest difficulty facing revegetation in the Hunter Valley coalfields, and Kelly (1979) observed likewise for Central Queensland. Broadcast seeding trials in Western Australia (Koch 1980), coastal N.S.W. (Floyd 1960), and Victoria (Dexter 1967) were largely unsuccessful due to simple drying of the seed beds. The effects of moisture stress on the germination of *Eucalyptus* species is critical to the success of artificial seed application in the field (Edgar 1977, Bachelard 1985).

Seed characteristics can affect the response to moisture availability. Bachelard (1985) showed that smaller seeds germinated better on drier surfaces due to smaller seeds having a larger proportion of the seed in contact with the soil surface and a smaller proportion exposed to evaporative stress. Hence, they can maintain a more favourable water balance for germination. Edgar (1977) suggested seeds of different species have different abilities to germinate under imposed moisture stress and that this was an ecological adaption. The ability of seeds to germinate can also be dependent on atmospheric humidity. Gibson and Bachelard (1985) showed that *Eucalyptus sieberi* seed would not germinate in dry air even though the substrate was wet. As a result, seeds would not germinate on the soil surface, however moist, except in humid weather.

Soil texture can affect the amount of water that can be held (Handreck and Black 1984). The smaller the pore, the more tightly the water is held. However, not all stored water is available to plants. Elliott (1986) showed that soils with a higher sand component have less available water, and this was expressed in lower field capacity and wilting point values. Figure 2.1 shows the approximate amounts of available and

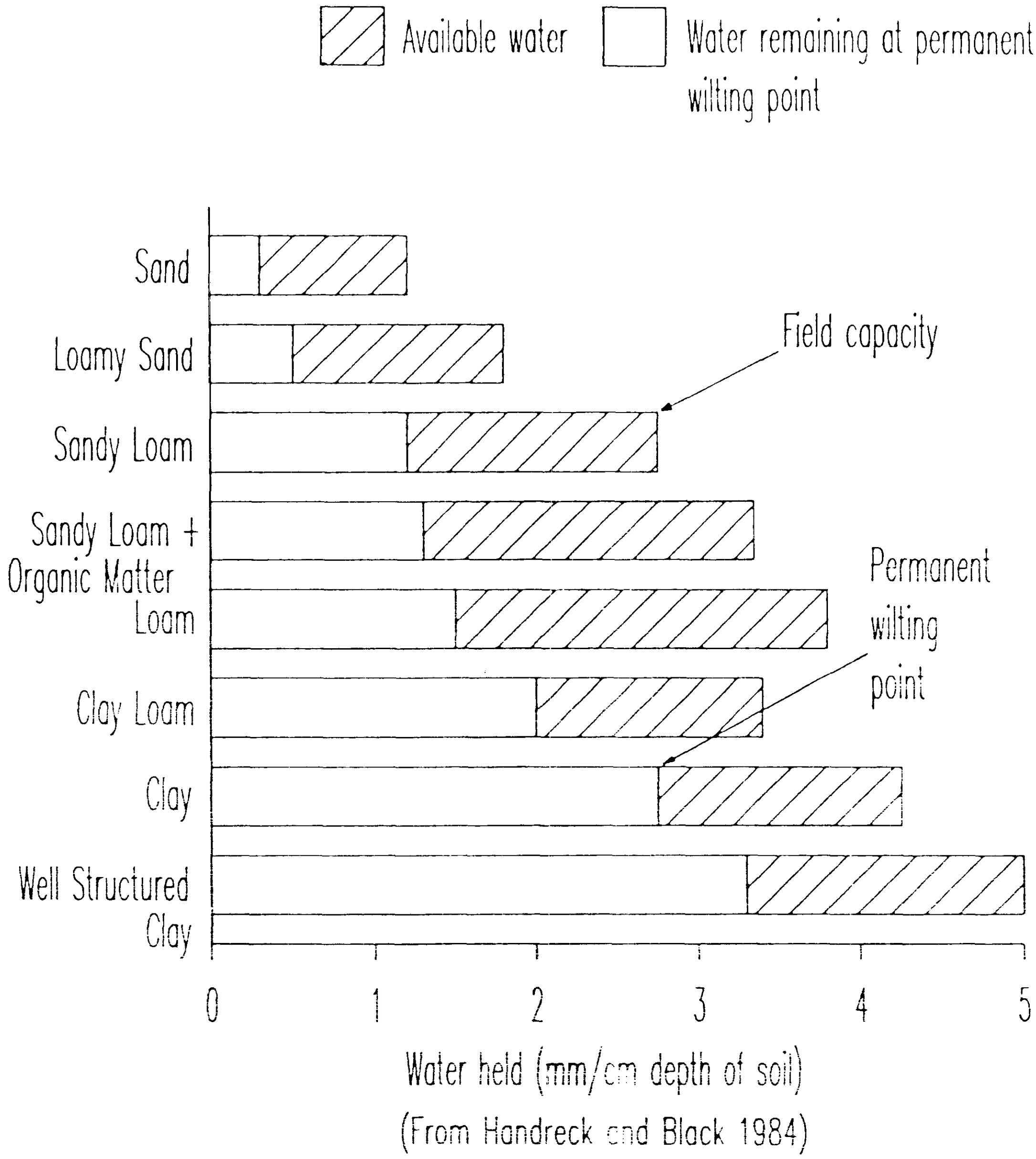

Figure 2.1 **Approximate amounts of available and unavailable water held by soils of different textures.**

unavailable water held by soils of different textures (from Handreck and Black 1984).

Differences in the texture of adjacent strata can also affect water retention and availability. Handreck and Black (1984) noted that a layer of coarse material underlying a soil of finer texture will cause that soil to remain wetter than if the layer was not present. They noted that finer grained clay materials tend to draw moisture both vertically and laterally from adjacent coarser grained layers. The relative texture and position of replaced surface spoil layers will therefore affect their water retention and water availability characteristics, and their consequent ability to support plant growth.

Poor structure in spoil can unfavourably effect water relations. Spoil can contain large quantities of rock. This increases available water in the short term by reducing particle surface area, and hence the retention ability of the spoil. However, in the long term the amount that can be stored and hence available to plants is reduced (Wilson 1985). Because spoil material generally lacks organic matter and can have high exchangeable Na levels, spoil can have a very low hydraulic conductivity, thus giving a low infiltration rate (Pederson *et al.* 1980). Elliott *et al.* (1980) found consistently lower infiltration rates in spoil than surrounding soils in the Hunter Valley, while Kelly (1978, 1979, 1980) documented very low infiltration rates in spoil in central Queensland. Elliott *et al.* (1986) also measured higher volumetric co-efficients of run-off from a gravelly-loam overburden compared to naturally occurring duplex soils and inferred lower moisture holding levels in the overburden. His results suggested that more moisture was held in surface layers of a topdressed site than in surface layers of overburden. This effect may result in plant roots concentrating at the surface of the topdressed site.

Despite low infiltration rates measured for some spoils, Elliott (1983a) showed that relatively more of the water which does infiltrate may be available for plant growth in overburden than in unmined soils. Ludeke (1973) also considered that spoil can have better available water capacities than the soil it replaces. Bradshaw (1983) suggested that even in spoil with very low available water capacity, there is only likely to be a water shortage at the surface, which will not cause problems for plants with reasonable root systems. Problems are more likely to be encountered for shallow rooting species and new germinants. In some spoil material, the available water may be limited in the surface layers because of loss through evaporation. Watt (1972) found that the top 6 mm of black clay soils can dry to below wilting point within a day or so after rain. Leslie (1965) suggested that rapid drying is indeed likely to be a problem in plant establishment on spoil.

Seed germination appears to be restricted or terminated at water potentials somewhat above wilting point. Different species have different requirements with respect to moisture availability for germination to occur (Watt 1974). The work of Hunter and Erickson (1952) suggested that seeds differ in inbibition capacity and that there may be a threshold value of soil water stress above which seed of certain species will not germinate. This would result in a variation in the ability of seed of different species to germinate at low soil water potentials (high tension).

2.3.3.4 Surface Crusting

One of the most pressing problems of many Australian soils is the hard-setting character of their surface. This problem is also common to spoil materials from mine operations (Doyle 1976, Hannan 1978, Kelly 1979, Russell 1978 and 1980, Verma and Thames 1975). These materials have poor rainfall infiltration capacity and, in many cases, probably less than two-thirds of the annual rainfall infiltrates the soil (Thompson *et al.* 1978). Crusting is one of the most important physical problems facing seedling establishment on mined sites (Russell 1978, Schessler and Droege 1965, Emmerton 1983). Agar (1984) considered that surface crusting under high temperatures may physically prevent eucalypt seedling emergence but produced no evidence to support its occurrence on mine spoil.

Where spoil consists of mudstone and shales, it may disintegrate rapidly to form a loose clayey material (Rai *et al.* 1974) (in a mineralogical sense), but with all particle sizes from coarse sand through to silt represented (Doubleday 1974). This wide particle size range results in rapid resorting of particles at the surface under the influence of rain, wind and vehicles (Doubleday 1974, Russell 1980),forming severe crusts (Plass 1974, Verma and Thames 1974, Russell 1978). A high ESP in spoil can also influence crust formation.

Unlike soil crusts which are limited to only several millimetres in thickness, spoils can display surface crusts of much greater depth (several cm). In unstructured material, particles have the potential to make maximum surface contact, resulting in increased crust strengths over those recorded in soils (Kemper *et al.* 1975).

2.3.3.5 Erosion

As a consequence of compaction, structural instability and poor water infiltration, enhanced erosion of the surface layer of spoil can occur. This results in the loss of plant nutrients, of plants growing in this layer and of plants buried by the colluvium (Schessler and Droege 1965). Exposure of 'fresh' spoil with its associated chemical and physical problems (Anderson and Briggs 1979) can also occur, together with siltation of surrounding waterways (Curtis 1974, Fogel *et al.* 1979).

An elevenfold increase in erosion losses was measured by Ringer *et al.* (1979) between a small non-rehabilitated surface mine and unmined catchments in central Wyoming in the United States. Increases in sediment yields of up to 1,300% above those of undisturbed catchments were reported by Verma (1977). Gilley *et al.* (1977) found erosion losses of 0.2, 18 and 74 t ha^{-1} for rangeland, spoil and applied topsoil over spoil respectively in western North Dakota in the United States using simulated rainfall. Hannan (1981) reported the following soil loss comparisons for mined and unmined sites at Howick and Foybrook mine sites in the upper Hunter Valley:

	Rainfall (mm)	Run-off Coefficient	Soil loss (kg ha^{-1})
Mined non-topsoiled plots	402.4	0.24	476
Mined topsoiled plots	378.8	0.18	1670
Unmined native pasture plots	340.0	0.20	1300

2.3.3.6 Colour, Albedo and Temperature

The colour of the spoil affects the proportion of incoming radiation that is reflected (i.e. its albedo) and this, in turn, affects the temperature of the material (Russell 1961). Dark spoil absorbs more heat than a light coloured spoil. A dark coloured spoil can reach high temperatures, causing scorching of plants (Le Roy and Keller 1972, Shirts and Bilbury 1976). Stiver (1949) cited by Khonke (1950) found temperatures on bare spoil to be 5° to 8°C higher than on surrounding bare soil, causing difficulties in the establishment of young seedlings. In Pennsylvania Deely and Borden (1973) recorded surface temperatures of 50° to 55°C and 60° to 70°C for dry, light coloured and dark spoil, respectively, with a corresponding air temperature range of 30° to 35°C. Very light coloured spoils can also cause plant death and stress by reflecting sunlight onto plants (Shirts and Bilbury 1976).

The surface temperature of spoil can also be affected by soil moisture. A bare wet soil reflects back about 7 to 10 per cent of incident energy on a sunny day, while a bare dry soil reflects about double this amount (Russell 1961). The absorbed energy is converted into heat and is dissipated through evaporation, heating of soil and air, and re-radiation.

Both the speed of germination and the proportion of seeds that germinate in any one seed lot are influenced by temperature (Grose 1965). The optimum constant temperatures for laboratory germination of commonly found Hunter Valley savannah woodland species (Story 1963, Croft 1978) are listed in Table 2.2 (Boland, Brooker and Turnbull 1980).

Table 2.2 Optimum germination temperatures of savannah woodland species native to the upper Hunter Valley, N.S.W. (After Boland, Brooker and Turnbull 1980)

# Species	Optimum Germination Temperature (°C)
E. albens	(25)
E. blakelyi	30; 25
E. crebra	30
E. camaldulensis	30
E. dawsonii	25
E. dealbata	25
E. fibrosa	(25)
E. maculata	25
E. melliodora	25
E. moluccana	25; 30
E. polyanthemos	25
E. punctata	25
E. tereticornis	25; 30; 35
**E. cladocalyx*	20

\# Nomenclature according to Pryor and Johnson (1971).

* Species native to South Australia, but adapted to local edaphic and climatic conditions and used in subsequent experiments.

() Brackets indicate only one seed lot tested.

2.3.3.7 Amelioration of Physical Limitations

Physical problems can be overcome by a variety of means.

Ripping and cultivation are universally accepted solutions to relieve compaction and increase infiltration (Forestry Comm. N.S.W. 1978, Bird 1982). Despite this acceptance Pickersgill (1982) showed that ripping depth did not affect tree survival on a rehabilitated bauxite mine and that deeper ripping did not lead to enhanced height and stem diameter. Similarly, Tacey (1979) found no significant effects on stem diameter which could be attributed to differences in ripping depth. At the Dongmen Project in China, Pegg (1987) indicated that local Chinese foresters like to carry our ripping to a depth of 40 to 50 cm. Project trials had shown such operations to be non-cost-effective and environmentally undesirable. Trials showed that a cultivation depth of 25 cm gave height and diameter responses for a range of *Eucalyptus* species equal to those from the intensive Chinese system. Rimmer (1979) considered the effects of ripping to be only temporary and reconsolidation may occur. Ripping can only be expected to give a positive growth response if compaction and infiltration are truly limiting. The previous studies did not state the degree of compaction and infiltration before or after ripping.

Little is known about the effects of compaction on the productivity of newly established ecosystems and how they can best be relieved permanently, although the cumulative effects of plants on resistance to consolidation can be demonstrated (Bradshaw and Chadwick 1980). Fitter and Bradshaw (1974) found that root growth and penetration in compacted soils can be promoted by fertilizer, but plants may still be drought prone.

In the short term, cultivation has been reported to decrease mechanical impedance and increase infiltration, storage of precipitation, aeration and soil temperature (Larsen 1964). The long term effects of cultivation are less clear, but there is some evidence that repeated cultivation can increase soil compaction over time through the destruction of soil structure leading to closer packing and fewer voids in the ploughed layer (Black 1987).

Calcium sulphate (gypsum) applications may improve surface structure and hence improve water infiltration (Barrow 1982, Grundy and Bell 1981). However, Coaldrake and Russell (1978) have pointed out that if spoils are high in electrolytes, especially Ca, little response would be expected from gypsum applications, although Power *et al.* (1978) recorded decreases in ESP of up to 50% after gypsum applications. Russell (1985) showed, using materials from open-cut coal mines in the Bowen Basin in Queensland, that the addition of Ca salts does not improve poorly structured spoil as a growth medium. This confirms other work by Coaldrake and Russell (1978) and Russell (1980).

One of the most common and important techniques used to overcome spoil structure problems is to add a layer of topdressing material to the mine spoil surface (Marshall 1983). Many studies have reported superior growth of plants when topsoil has been added to coal mine wastes (Hannan 1979a, b, Kelly 1979a, b, Koch 1980). However, while pre-stripped topsoil is often considered a panacea for overburden shortcomings, its quality needs critical evaluation. Topsoil is not always beneficial nor an improvement on overburden material. Kelly (1979a, b) reported revegetation has been achieved with greater success without topsoil spreading. Dyson (1985) showed that after three years, there was little difference between the height of trees planted into topdressed and raw overburden material at Ravensworth No. 2 Mine in the Hunter Valley.

In a similar vein, organic mulches have been used successfully in many instances (Aldon 1978, Carpenter *et al.* 1978, Hannon 1979b). Organic mulches have been used to improve spoil structure, the microclimate, germination and seedling survival, infiltration, and reduce runoff and evaporation (Doyle 1976). Other materials have also been used at Saraji Mine in the Bowen Basin Coalfield of Queensland; an amendment of stone mulch, prepared from rock that has been separated from coal, was used to alleviate surface crusting and poor infiltration of spoil.

Generally, mulches affect germination and plant growth by improving moisture permeability and retention (Clemens 1984). Clemens showed that species can react quite differently to different types of mulch, possibly due to the effects on seedling emergence through the mulch or through the preferential effect changed seed bed conditions may have on the germination of some species over others. However, care must be taken to ensure that the depth of coverage must not be greater than the germinant's ability to extend its hypocotyl and expose the cotyledons to light (Cremer 1965). Larger seeds generally have the ability to emerge from greater depths (Jacobs 1955).

Vegetation mulches can be used to reduce fluctuations in the soil surface temperatures, while night temperatures are higher due to the mulch reducing the flow of heat from the soil to the air (Geiger 1957). Where low temperatures may restrict plant growth, darker mulches may improve early emergence and growth by increasing the ground temperature. Fairbourn and Gardner (1972) found that the application of coal mulch improved test yields due to the increase of soil temperatures by 2° to 3°C. A vegetative mulch can also have a detrimental effect by reducing the surface soil temperature in autumn and spring (Russell 1961). This effect can delay the time during which the soil becomes warm enough for the seed to germinate and also can delay the time it takes to start active growth in the spring. Mulching can also increase surface rooting by increasing water retention (Russell 1961). While this may increase phosphate uptake, it may reduce the long term drought hardiness of the plant.

2.3.4. Weathering of Spoil

Natural weathering can change the physical and chemical properties of overburden exposed to the atmosphere. Spoil weathering and the initiation of soil forming processes may radically change the spoil as a growth medium.

Overburdens display variable rates of degradation. Physical breakdown of shale or mudstone material can be rapid, while sandstone breaks down more slowly (Doubleday 1974). Initially, the surface of spoil material breaks down quickly (Geyer and Rogers 1972, Rai *et al.* 1974) with a rapid rate of physical breakdown occurring in the first three to five years, after which weathering slows dramatically (Schessler and Droege 1965). Few large rocks are found on spoil surfaces after 30 years (Ashby and Kolar 1977). Final products include residual clay minerals in the clay and silt fraction, sand, small rock fragments and the formation of some new secondary minerals (Khonke 1950).

Elliott (1983b) noted an increase in the fine earth fraction at the surface of grey, carbonaceous very fine sandstone overburden at the Ravensworth No. 2 open-cut Mine in the upper Hunter Valley, and noted that this was consistent with the development of surface crusts on these materials. Macleod (pers. comm. cited in Elliott 1983b) studied similar overburden and considered that weakening of aggregating forces during weathering would lead to dispersion of clay material with high ESP values.

Unfavourable soil physical and chemical characteristics can be alleviated over time, although the processes which build up structure are slow. Russell (1977) showed that bulk densities can decrease with time. At Glacier Bay, in Alaska, bulk densities of glacial moraines changed from 1.5 g cm^{-3} to 0.7 g cm^{-3} in 100 years (Crocker and Major 1955). Schafer *et al.* (1981) reported the development of some re-aggregation of particles at 25cm depth in Montana coal mine spoil after 25 years. Ashby and Kolar (1977) found that soil development had progressed rapidly on recontoured 30 - 50 year old strip coal mines in Illinois and Indiana in the United States. This included incorporation of organic material, profile development, complete weathering of most sedimentary rocks, and extensive root development. Perhaps the most significant study undertaken on open-cut coal mines in the Hunter Valley to date was made by Elliott (1981). He studied old spoil at Foybrook Colliery in the upper Hunter Valley, consisting of fine-grained sandstone with minor mudstone bands from above the Liddell Seam in the Wittingham Coal Measures. The material received no topsoil, fertilizer or artificially applied seed. The site quickly colonized with native grass species. After 30 years, the material was well structured, porous and free draining. In comparison with adjacent natural soils, the material had a considerably higher P content, and about the same N content. The study indicated that soils which eventually form from coal mine spoil will certainly support healthy vegetation and may be superior to the duplex soils in the district. Hannan (1981) therefore raised the question as to whether the replacement of 'topsoil' over reshaped spoil dumps actually assisted or hindered natural soil-forming processes.

2.4 Foliar Nutrient Analysis

Foliar analysis has been used as an aid in nutrient deficiency diagnosis (Turner and Lambert 1986, Ballard 1977), in interpreting responses in fertilizer trials (Richards and Bevege 1969), in establishing critical levels for crop-logging (Bevege and Richards 1972) and in examining site growth relationships for predicting potential growth (Jackson and Gifford 1974). With the exception of crop-logging these uses make foliar analysis an important aid in spoil related growth studies. Lambert (1984) considers foliar analysis to be a valuable tool in tree nutrition but only when objectives are clearly defined.

Both McColl (1969) and McColl and Humphreys (1967) showed significant correlations between leaf P and soil P for the genus *Eucalyptus*. McColl also showed similar correlations between bark and soil Ca. There are relatively few other reports where such correlations have been observed between soil and tree tissue nutrient levels, although many attempts have been made (e.g. McVickar 1949; Metz *et al.* 1966).

Bevege (1978) predicted growth responses of *P. patula* on the basis of multiple regression analysis linking height growth (Site Index) with foliage and soil nutrient status. Good correlations have been established between the concentration of a nutrient in a particular plant part and the relative growth of *Eucalyptus* grown in solution culture (Kaul *et al.* 1966, Lacey *et al.* 1966). While such relationships are more difficult to establish under field conditions careful examination of young trees by Bhimaya and Kaul (1966) and Lamb (1977) have shown they do exist.

Ward *et al.* (1985) showed that higher leaf N concentrations generally suggest a better nutritional status and higher growth potential. Bell (1985) suggested that because of the range of both the N and P critical leaf concentrations (the concentration of the element in the tissue producing 90% of maximum yield) the use of the N:P ratio may be a more useful index of plant health. A relative narrow optimum N:P range of 5 to 15 appears to exist for most *Eucalyptus* species (Lamb 1977, Lacey *et al.* 1966, Cromer *et al.* 1981, Bell 1985). Cromer *et al.* (1981) showed that *E. globulus* which had higher ratios than this responded to P and those with lower ratios responded to N. Data for other species were not conclusive.

Schönau (1981) found the mean concentrations of N and P in *E. maculata* to be 1.23 and 0.06 per cent in dry matter respectively with the N : P ration being 20. Wise and Pitman (1981) found similar levels in short rotation *E. maculata* plantations of 1.29(N) and 0.07 (P) per cent with a N : P ratio of 18. However, Creswell (1987) found the N and P concentrations in native *E. maculata* to be 1.13 and 0.145 per cent, respectively, with an N : P ratio of 8. Lambert (1984) suggested that results for individual species need to be interpreted in relation to stand age; whether the effect of age is a result of soil changes or physiological effects; nutrient limitations and interactions; and the modifying effects of the environment. It also appears that for individual species nutrient levels and ratios may vary with factors such as season of sampling, phenology of leaf and crown position (Schönau and Herbert 1981) as well as site factors (Cromer *et al.* 1981).

In addition to N and P, Schönau (1981) also showed foliar concentrations of K, Ca, Mg, S and Zn conformed closely to the rate of height growth. Only Fe showed an inverse relationship. Schönau and Herbert (1981) showed that for satisfactory growth of *E. grandis* the foliar N : P ratio should be between 10 and 16, that for P : K between 0.21 and 0.26 and that for N : K about 3.

2.5 Weed Competition

In the Australian environment, tree planting is seldom successful if grass and broad-leaved weeds are allowed to compete with the newly planted trees (Menzies and Chavasse 1982). Boden (1965) found that, without removal of weeds around newly planted trees, growth was only half to three-quarters of that which occurs under weed-free conditions. Jack (1970) found that 1-2 years growth of radiata pine (*Pinus radiata*) can be lost due to competition during establishment from herbaceous weeds. This lost growth is not made up later. Early control of weed competition will maximise early growth of desired plant species and their survival.

Initially, open-cut coal mining produces a weed-free environment rarely found in nature. Consequently, an ideal situation is provided for the first natural or artificially applied seed or seedlings. Native species introduced under these conditions at this stage of rehabilitation suffer little competition from weed species.

Competitive weed species can be introduced in pre-stripped topdressing material or by sowing pasture species. Wind-blown seed will establish over time, but this effect is slower than the other sources of weed introduction.

Many exotic pasture species in rehabilitation are adapted to rapidly utilize available moisture and nutrients at an early stage. The comparatively protracted establishment of many species from seed, renders them susceptible to competition (McMurray 1985). The degree of competition that can be tolerated depends on the limiting factors of the site and the sensitivity of the preferred species to these (Brown and Hall 1968). Generally, it has been found that the better the weed control, the higher the percentage establishment of native species from seed (Venning *et al.* 1985, Irving 1986), and the better the growth (Irving 1986, Wise *et al.* 1980) and subsequent survival (Revell and Deadman 1976).

The main ways in which weeds might restrict growth are through competition for water (Larson and Schubert 1969), nutrients (Greenham 1957) and light (Strotham 1967). Allellotropism can also be a factor (Jameson 1961), but this effect is not widely reported. According to Greenham (1957), the marked restriction of tree growth by weed competition in the early years of establishment is caused primarily by competition for soil moisture and, to some extent, for N. Waring (1972) found that removal of weed competition by herbicide spraying increased the N content in tree foliage and that responses to N and P fertilizers depended on the degree of control of weed competition; in some instances competition, even at low levels, neutralized the effect of fertilizer. Conversely, weed control can substitute for N fertilizer (Richards 1967).

Removing competition is, therefore, essential for establishing native species, either from seed or seedlings. Other techniques are not effective. Attempts to stimulate tree growth by fertilizing also stimulate luxuriant weed growth (Hilton 1967), which further compounds competition problems. Richards (1967) however showed that repeated applications of N fertilizer eventually stimulated the growth of hoop pine seedlings, despite increased grass competition.

2.5.1. Pre-Emergent Herbicides

Large areas of reformed open-cut coal mines have been traditionally stabilized with a perennial pasture sward prior to native tree planting. Unless this pasture is controlled, tree survival and growth is greatly reduced. Some success has been achieved with scalping (Hall 1985), but the scalped strips are quickly reinvaded with weeds. The main requirement is for herbicides that can be safely applied over newly planted trees and/or sown seed and which will give long lasting pre-emergent control of weeds.

Tree species vary in their tolerance of herbicides (Hall 1985) and while effective and safe pre-emergent herbicide treatments have been developed for many commercially important forest and orchard species, little is known of the tolerance of Australian native tree species to pre-emergent herbicides.

Hall (1985) found that planted *E. maculata, E. tereticornis, E. moluccana, Acacia saligna* and *Casuarina cunninghamiana* seedlings were tolerant of oxadiason and fluazifop-butyl. With the exception of *A. saligna* whose growth and survival was affected they were all tolerant of a mixture of propazine and propyzamide. Similarly, Nazer and Clark (1984) found mixtures of naproamide and propyzamide with methazole or simazine were useful in controlling annual weeds around common landscape trees in Canberra during establishment. The effect lasted for a season, or longer, from a single application.

The main advantage of pre-emergent herbicides over pre-planting knockdown herbicides has been their sustained control over longer periods. However, pre-emergent herbicides are usually rapidly broken down on the soil surface, and for maximum results, need to be incorporated into the soil soon after application. If rainfall does not occur within 1 - 2 weeks following application, or if cultivation is not undertaken, they become less effective (Nazer and Clark 1984).

The effect of pre-emergent herbicides on newly germinated native seedlings, as opposed to established seedlings, has received little study. However, as many pre-emergent herbicides e.g. nitroanilines, work through inhibiting root elongation (Ashton and Crafts 1973), their effect on new germinants could be expected to be more dramatic. Weatherly (1985) and Sharp (1985) found that atrazine improved establishment of direct seeded native species. Venning *et al.*(1985) had inconclusive results with Tri-fluralin and Tri-allate. McMurray (1985) also had inconclusive results and showed that, while Tri-fluralin suppressed grasses for one month, it had a marked inhibitory effect on eucalypts, even at the lowest rate.

Whitham (1982) found that simazine, while increasing growth through improved weed control, also stimulated native plant growth at sub-toxic levels. Similarly, Rice *et al.* (1963) reported that apple tree (*Malus sylvestris*) grew more when weeds were controlled with simazine, than with black plastic or hoeing. The increase in growth was attributed to increased N absorption or improved N metabolism.

CHAPTER 3

DESCRIPTION OF HUNTER VALLEY MINE SITES

3.1 General Description of Hunter Valley Conditions

For the purpose of this study the Hunter Valley has been divided into two major areas; the upper and lower Hunter Valley. General broad conditions within these areas are discussed. The main coal measures occur on relatively smaller areas within those two broad zones. Most of the experiments and trials were located on mine sites or utilized spoil material from the Wittingham Coal Measures located in the upper Hunter Valley and particularly from Hunter Valley No. 1 Mine. For this reason, more specific details have been provided for Hunter Valley No. 1 Mine. Conditions at Hunter Valley No. 1 Mine are considered typical of those prevailing at the majority of mines in the upper Hunter Valley.

3.1.1. Location

The location of the Hunter Valley is shown in the insert in Figure 3.1 The location of the upper Hunter Valley Coal Field and of specific mines involved in the study can be seen in Figure 3.1

3.1.2. Climate

Tweedie (1963) described the climate of the upper Hunter Valley as subhumid with hot summers and cool to cold winters. Conditions in the lower Hunter Valley are more humid in summer with milder summer and winter conditions. Two meteorological stations were selected as being representative of conditions in both the upper and lower valley. Jerry's Plains was located centrally to many coal mines in the upper Hunter Valley, while East Maitland was considered representative of conditions in the lower Hunter Valley.

Figure 3.1 Locality map of Hunter Valley showing trial collieries and major coal measures.

3.1.2.1. Rainfall

Upper Hunter Valley

Annual

Long Term rainfall statistics for Jerry's Plains are shown in Table 3.1. The average annual rainfall over a period of 101 years is 631 mm at Jerry's Plains (Bureau of Meteorology 1985) with an average annual variability of 24 %. An isohyetal map of the average annual rainfall experienced in the Hunter Valley shows a general relationship with relief and distance from the sea (Figure 3.2). From a semi-arid core near the confluence of the Hunter and Goulburn Rivers (less than 500 mm ann^{-1}), rainfall increases steadily in all directions except westward.

Monthly

Monthly rainfall averages based on 101 years of records show that January and February are the wettest months while the period from April to October is the driest (Table 3.1). The average number of wet days per month is 7. The upper Hunter Valley is characterized by late summer, high intensity, short duration storms which result in higher falls of rain per wet day during summer than in winter. Monthly rainfall variability is lowest in December and January and highest in May and June.

Lower Hunter Valley

Annual

Long term rainfall statistics for East Maitland are shown in Table 3.1. The average annual rainfall over a period of 87 years is 891 mm at East Maitland (Bureau of Meteorology 1985) with an average annual variability of 21 %. Average annual rainfall at East Maitland is 30 % higher than at Jerry's Plains.

Table 3.1 Summary of long term rainfall characteristics for Jerry's Plains and East Maitland.

(a) Jerry's Plains Meteorological Station (101 years)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
1	79	68	59	44	40	49	44	36	40	51	55	66	631
2	45	65	65	63	87	78	60	53	59	53	68	52	24
3	8	7	7	6	6	7	7	7	6	7	7	7	82
4	9	7	8	8	7	6	8	4	6	6	9	11	8

(b) East Maitland Meteorological Station (87 years)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
1	89	90	93	85	66	86	62	55	57	62	59	87	891
2	58	57	54	66	80	73	75	59	64	66	63	53	21
3	8	8	8	8	7	9	8	7	7	7	7	7	91
4	11	11	12	11	9	10	8	8	8	9	8	12	10

1. Mean rainfall (mm)
2. Rainfall variability (%)
3. Mean number of rain days
4. Rain per wet day (mm)

(After Bureau of Meteorology 1985)

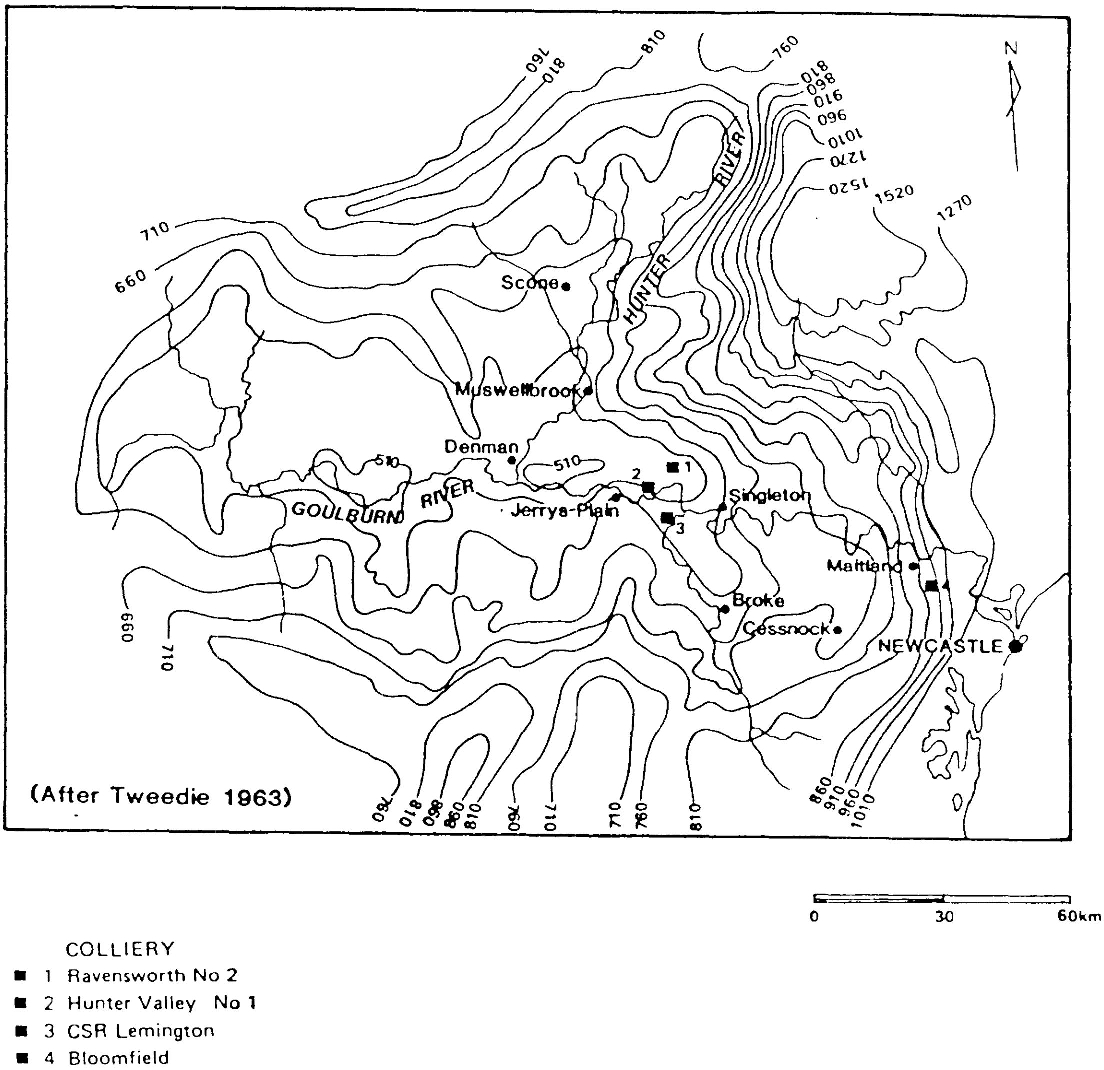

Figure 3.2 Isohyets of mean annual rainfall distribution (mm) for study area.

Monthly

Monthly rainfall trends at East Maitland are similar to those at Jerry's Plains although mean monthly rainfall figures are higher. The average number of wet days per month is 7.5. This figure is similar to that for Jerry's Plains as is monthly rainfall variability.

3.1.2.2 Temperature

Upper Hunter Valley

Long term temperature statistics for Jerry's Plains are shown in Table 3.2. High temperatures are experienced at Jerry's Plains during the summer with January being the hottest month. Heat-wave days (temp.> 35°C) may occur from October to March. Cooler temperatures are experienced during winter with July being the coldest month. Winter minimums are low, with frosts (< 0°C) commonly occurring from May to September.

Lower Hunter Valley

Long term temperature statistics for East Maitland are shown in Table 3.2. Temperature conditions experienced at East Maitland are milder than at Jerry's Plains. Summer maximums are lower and winter minimums are higher. East Maitland has only one third the number of frost days as Jerry's Plains and only 60% of the number of heat-wave days.

3.1.3 Topography, Soils and Vegetation

Upper Hunter Valley

Topography

The areas currently being mined occur within gently sloping to undulating country with gradients ranging from 5% to 25%. Some alluvial areas obviously have lower gradients. The northern part of the Hunter

Table 3.2 Summary of long term temperature characteristics for Jerry's Plains and East Maitland.

(a) Jerry's Plains Meteorological Station (101 years)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
1	33	32	30	25	21	18	18	20	24	28	31	33	27
1	17	16	15	11	7	5	4	4	7	10	13	15	10
3	25	24	22	18	14	11	11	12	15	19	22	24	18
4	7.3	6.1	4.1	0.4	0	0	0	0	0	2.4	5.2	7.4	32.9
5	0	0	0	0.4	1.8	4.5	6.8	4.0	1.0	0	0	0	18.5

(b) East Maitland Meteorological Station (87 years)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
1	31	30	28	25	21	18	18	20	23	26	29	30	25
2	17	17	16	13	9	7	6	7	9	12	14	16	12
3	24	24	22	19	15	13	12	13	16	19	22	23	18
4	5.4	3.5	1.4	0	0	0	0	0	0	1.0	3.7	4.5	19.5
5	0	0	0	0	0.3	1.4	2.7	1.9	0.2	0	0	0	6.5

1. Mean Maximum Temperature (°C)
2. Mean Minimum Temperature (°C)
3. Mean Temperature (°C)
4. Heat-wave Days (> 35°C)
5. Frost Days (< 0°C)

(After Bureau of Meteorology 1985)

Valley is bounded on three sides by mountain ranges rising to a maximum of about 1,500 metres.

Soils

The soil types in the upper Hunter Valley can vary greatly. They are predominantly duplex in nature and can be dispersable and saline. The structure of the A horizon is often quite poor, resulting in hard setting surface characteristics, especially if the soil has been mechanically disturbed a number of times during the stripping - stockpiling -respreading phase of mining. A bleached A_2 horizon often exists. B horizons tend to be highly pedal (Veness 1983). Below this layer, weathered rock may be found to a depth of 15 metres. Beneath this fragmented material is the bedrock. The rock types include mudstone, siltstone, sandstone, conglomerate and igneous intrusions. These types may occur in any combination or sequence, although sandstone and coarsely weathered mudstone tend to predominate (SPCC 1983).

Vegetation

Prior to European settlement, the dominant vegetation type of the area was Savannah woodland consisting predominantly of *E. moluccana, E. crebra, E. tereticornis* and other woodland species (Table 2.2). In the more accessible areas the vegetation has been changed greatly by the clearing of the original woodland and the destruction of many of its grasses through uncontrolled grazing (Story *et al.* 1963). The process of mining has also been responsible for major changes in the vegetation occurring in these areas.

Lower Hunter Valley

Topography

The main coal mining area is dominated by ridges with a major trend running north-south and a smaller trend running east-west. Most slopes are in the range of 10 to 18 degrees with a small percentage of slopes being in excess of 18°. Other major topographic features in the area include the Sugarloaf Range and Hexham Swamp to the west of Newcastle, and Lake Macquarie to the south-west.

Underground workings in some areas have resulted in the development of sink holes. These sink holes are generally shallow and small in area.

Soils

The soils in this area have been described by Croft *et al.* (1981). In the major mining areas soils comprise mainly gradational profile type soils. Uniform soils occur in small areas. Soil cover is relatively thin over the major mining sites. Soils often have a low to very low organic content and are frequently very friable. Topsoils are mainly free draining with low to moderate erosion potential. Gradational soils frequently have a grey to grey-brown sand to sandy loam topsoil up to 100 mm in depth. Below this is a gradual transition to yellow-fawn sandy clay loam which is up to 600 mm in depth. The uniform soils are grey sandy loams up to 200 mm thick. They are discontinuous in cover and very variable in thickness.

Vegetation

Prior to European settlement, the area was completely wooded. Eucalypts were the natural dominants. They are tall and dense in more sheltered valleys and gullies, but where conditions become progressively more severe the eucalypts become progressively sparser and floristically different and shorter. The main coal mining area is dominated by dry eucalypt sclerophyll forest. The canopy averages about 16 metres in height, with frequent light breaks, the commonest trees being *Angophora costata, A. floribunda, E. acmenioides, E. gummifera, E. maculata, E punctata,* stringybarks, and broad-leaved ironbarks. The forests vary greatly in their species composition and proportions from place to place (Story *et al.* 1963).

3.1.4. Geology

Upper Hunter Valley

The locations of the main coal measures in the Hunter Valley are shown in Figure 3.1. There are two distinct sets of Permian coal-bearing sediments in the upper Hunter Valley (Britten 1977). The lower of these are the Greta Coal Measures, which can be correlated with similar strata outcropping in the Cessnock / Maitland district. In the upper Hunter, these coal measures are worked at several locations in close proximity to the township of Muswellbrook. Above the Greta Coal Measures, but separated from them by the marine Maitland Group, is the Singleton Super-Group. The Wollombi and Wittingham Coal Measures form, respectively, the upper and lower coal-bearing sections of the Singleton Super-Group. At the present time, the majority of coal production in the district comes from the Wittingham Coal Measures.

Lower Hunter Valley

The main strata outcropping in this region are the Permian Newcastle Coal Measures. The geology of these Measures has been described by Britten (1977).

The Newcastle Coal Measures consist of a sequence of conglomerates, sandstones, mudstones, shales, claystones, tuffs and coal seams, varying in thickness from 100 m at Awaba to 400 m at Swansea. The measures occupy a shallow synclinal structure (the Macquarie Syncline) which has a general north - northwest to south - southwest trend and a southerly dip.

The Tomago Coal Measures underlie the Newcastle Coal Measures. the overlying Triassic sediments are exposed to the west in the Sugarloaf Range.

3.2 Description of Conditions at Hunter Valley No. 1 Mine

3.2.1 Location

Most of the experiments in this research programme were conducted at Hunter Valley No. 1 Mine (Lat. S 32° 30'; Long E 150° 54') on used spoil materials from this mine. The mine is approximately 30 km northwest of Singleton, N.S.W. (Figure 3.1) and is approximately 80 m above sea level and adjacent to the Hunter River.

3.2.2. Climate

Long-term meteorological data from Jerry's Plains Post Office located 7 km to the west of Hunter Valley No. 1 Mine have already been described in Section 3.1.2. A meteorological station located at Hunter Valley No. 1 Mine recorded weather conditions at the site during the experimental period June 1985, to May 1987, on a 5 day a week basis. The meteorological station was located approximately 900 m to the north-west of the experimental sites.

3.2.2.1 Rainfall

The monthly total and the number of days of rain in each month for Hunter Valley No. 1 Mine are shown in Table 3.3. When compared with the long term monthly means for Jerry's Plains it was apparent that twelve of the twenty-four months of the measured growing period were below average, with a pronounced dry period occurring between February and July, 1986. In 1986 rain fell on 66 days at Hunter Valley No. 1 Mine, compared to a long term mean of 82 at Jerry's Plains. Rainfall in the last half of 1985 and the first half of 1987 was generally higher and more regular than for equivalent periods in 1986.

Table 3.3 Rainfall data for Hunter Valley No. 1 Mine (Upper Hunter Valley) for duration of the study.

1985

Month						Jun	Jul	Aug	Sep	Oct	Nov	Dec
No. of * days rain						4	5	9	9	10	9	5
Monthly * Total (mm)						30	29	42	54	174	61	44

^ Sowing 1985 (H.V. No. 1 - Exps. 1, 2 and 3; Ravensworth No. 2 - Exp. 6).

1986

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
No. of * days rain	6	5	0	2	8	2	10	8	5	8	10	2
Monthly * Total (mm)	90	15	0	2	23	12	36	74	77	33	105	12

^Sowing 1986 (H.V. No. 1 - Exps. 4 and 5).

1987

Month	Jan	Feb	Mar	Apr	May
No. of * days rain	6	5	7	1	8
Monthly * Total (mm)	102	5	102	22	45

^Study completed

* After Hunter Valley No. 1

3.2.2.2 Temperature

Temperature figures for Hunter Valley No. 1 Mine for the study period are shown in Table 3.4. Mean monthly maximum temperatures around sowing time in 1985 and 1986 were very close to the long term averages for Jerry's Plains (Table 3.2). Mean monthly minimum temperatures were slightly higher for 1986 than the long term average for Jerry's Plains.

3.2.2.3 Evaporation

Evaporation details are not only important in indicating the rate at which water is lost from the soil but also in determining transpiration losses by plants. Martin and Specht (1962) found that transpiration rates in a dry sclerophyll eucalypt forest were related to pan evaporation.

Evaporation data have been collected at Hunter Valley No. 1 Mine using an Australian standard tank over a seven year period, and are shown in Table 3.5 together with the actual evaporation for the study period.

Total monthly evaporation in the six months following sowing in 1985 (654 mm) was lower than the average mean monthly evaporation for this period (719 mm). However, the total monthly evaporation in the six months following sowing in 1986 (641 mm) was considerably higher than the average evaporation for this period (564 mm). The increase was largely a result of high evaporation in April, 1986 (the month of sowing).

Table 3.4 Temperature data for Hunter Valley No. 1. Mine (Upper Hunter Valley) for duration of the study.

1985

Month	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean Monthly * Max.	17	17	18	22	25	26	30
Mean Monthly * Min.	6	6	6	9	12	14	17
Mean Monthly *	12	12	12	16	19	20	24

^Sowing 1985 (H.V. No. 1 - Exps. 1, 2 and 3)(Ravensworth No. 2 - Exp. 6)

1986

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean Monthly * Max	31	30	32	29	22	18	17	18	22	24	26	29
Mean Monthly * Min.	16	18	18	14	11	6	6	6	8	11	13	13
Mean Monthly *	24	24	25	22	17	12	12	12	15	18	20	21

^Sowing 1986 (H.V.) No. 1 - Exps. 4 and 5)

1987

Month	Jan	Feb	Mar	Apr	May
Mean Monthly * Max.	33	32	26	25	20
Mean Monthly * Min.	18	18	14	13	10
Mean Monthly *	26	25	20	19	15

^Study completed

* After Hunter Valley No. 1.

Table 3.5 Evaporation data (mm) for Hunter Valley No. 1. Mine.

(a) Over 7 year period (up to 1987)

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Evap. Total (mm)	280	181	164	120	76	56	71	95	146	161	190	219	1759

(b) For duration of the study

	Year	Month:	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Evap.	1985							62 ^Sowing	91	87	123	131	160	207
Total	1986		235	184	164	203 ^Sowing	77	64	76	74	147	186	173	245
(mm)	1987		207	207	144	88	75							

^Study completed (Final measure)

3.2.3. Topography, Soils and Vegetation

Topography

The topography of adjacent unmined areas consists of moderately steep rounded hills with slopes up to 18°. The experimental sites occur within 600 m of each other. The sandstone and topdressed sites had an average gradient of 3° with a western aspect. The shale site had a slope of approximately 11° with a southern aspect.

Soils

Prior to mining, soils at Hunter Valley No. 1 Mine were predominantly brown solonetzics and red/brown podzolics (van de Graaf 1963) derived from fine-grained lithic sandstones (Croft 1978)› The soils were duplex in structure and occurred extensively over the area. A general profile description of each soil type is presented in Appendix 1.

The soils existing prior to mining were stripped, stockpiled and respread on the topdressed site. Due to consequent mixing it is not possible to classify the respread material other than by characterizing the physical and chemical properties as described in Chapter 4.

Vegetation

Croft (1978) identified the plant species on the mine lease and adjacent areas. In addition, he described the distribution of the major plant associations, based on dominant vegetation types present. Due to complete inversion of the strata during mining the relevance of pre-mining vegetation to post-mining revegetation is greatly reduced. Pre-mining soil types can only be a very approximate guide to revegetation after mining and only where topdressing material is respread. Even here the respread material may be radically altered by the stripping, storage and respreading processes.

3.2.4 Geology

Hunter Valley No. 1 Mine is extracting coal from the Mount Arthur, Pierce and Vaux seams from within the Wittingham Measure. Overburden strata from within Hunter Valley No. 1 Mine are considered to be representative of materials at other mines within the Wittingham Coal Measures. The process of mining and replacement of those materials has resulted in extensive mixing of the strata.