

PHYSICAL AND CHEMICAL FACTORS
AFFECTING NATIVE TREE ESTABLISHMENT
ON REFORMED OPEN-CUT COAL MINE SITES
WITHIN THE HUNTER VALLEY

Mark Warren Burns. B.Sc. (Forestry)

A thesis submitted for the degree of
Master of Resource Science in the New
England University, Armidale, New
South Wales.

Department of Ecosystem Management
May 1988

DECLARATION OF ORIGINALITY

I certify that the substance of this thesis has not already been submitted for any degree and is not being currently submitted for any other degree.

I certify that, to the best of my knowledge, any help received in preparing this thesis, and all sources used, have been acknowledged in this thesis.



M. W. BURNS.

ABSTRACT

This study details the results of the first systematic investigation of the factors affecting native tree establishment on coal mine spoil within the Hunter Valley. Previous research had largely concentrated on the use of replaced topdressing materials which primarily consists of soil B horizon. The suitability of other spoil material e.g. sandstone, shale and mudstone substrates as media for tree growth, has received little attention. This lack of basic information has meant that this study was intentionally broad and investigated aspects of tree establishment on a wide range of substrates which may deserve more detailed attention.

The major aim of the research described herein was to investigate the suitability of a range of substrates for native tree establishment and to develop practical, low cost tree establishment techniques. Specific objectives included identification of physical and chemical spoil characteristics which may be limiting to the germination, survival and/or growth of native tree species.

Two major investigation techniques were used. Firstly, controlled glasshouse experiments using potted materials, allowed control of external variables in order that specific problems affecting germination, survival and early growth could be examined. Field experiments further examined glasshouse results and investigated the effect of different substrates and treatments on germination, survival and growth.

Seed germination was consistently inferior on topdressing materials in glasshouse experiments compared to other substrates. The effect of substrate in field experiments was much more variable and there was no single or obvious explanation for differences in germination. Despite this, germination levels on most substrates trialled in the field were considered good. Deep ripping and the use of straw, and to a lesser degree chitter mulch, were the only field treatments that enhanced germination. In both glasshouse and field experiments there was no consistent advantage to germination in adding fertilizer at sowing time.

Survival in the glasshouse appeared to be affected by pre-emergent damping-off. Differences in field survival appeared to parallel differences in substrate moisture availability.

In glasshouse experiments, topdressing materials produced consistently superior growth of plants compared to other substrates. The effect was considered to relate to better nutrient availability and superior soil structure in topdressing materials. In field experiments there was no consistent growth advantage in using topdressing material and results varied between collieries and between experiments within each colliery. No single factor could be attributed to substrate-induced growth differences, although variation in the depth of topdressing material and the coarse rock fragment within substrates were considered important.

In glasshouse experiments, P was the most important deficient nutrient in plant growth and the only nutrient consistently deficient in all substrates. Nitrogen and S were also deficient in most substrates. In glasshouse experiments *Eucalytus maculata* was much more sensitive to nutrient addition and nutrient omission than *Casuarina glauca*. Field nutrient responses were not adequately tested.

The use of a millet cover crop did not affect native species germination or survival. However the growth of native tree species was reduced with increased millet sowing rates and the effect was attributed to increasing competition for soil nutrients. The need for surface stability during the relatively protracted development of native tree species led to an investigation of pre-emergent herbicides.

The pre-emergent herbicides Surflan and Diphenamid were found suitable for field use when tested against four planted native tree species and two application rates. However, only Diphenamid was found suitable for use with directly sown seedlings under glasshouse conditions.

There was a clear preference by some species for particular substrates. However it was not possible to determine what physical or chemical spoil effects were involved in this selective response.

The study clearly demonstrated the suitability of most substrates for native tree establishment using direct seeding techniques. In field trials there was no obvious clear-cut advantage to native tree establishment by using topdressing material. Germination, survival and growth of native tree species on most substrates was considered adequate and dominant trees on all substrates were healthy and vigorous. The main advantage of topdressing material appeared to be in the better establishment of pasture species.

Direct seeding proved to be a much cheaper tree establishment technique than traditional seedling planting. This, together with other advantages such as high stocking rates, ease of establishment and varied stand structure, makes direct application of native tree seed a viable and attractive revegetation option for use on recontoured open-cut coal mines in the Hunter Valley.

TABLE OF CONTENTS

	Page
LIST OF TABLES	xi
LIST OF FIGURES	xviii
LIST OF PLATES	xxii
CHAPTER 1	INTRODUCTION
	1
1.1	A perspective on Open-cut Coal Mine Rehabilitation in the Hunter Valley
	1
1.2	History of Tree Planting on Spoil in The Hunter Valley
	2
1.3	General Factors Affecting the Nature and Suitability of Surface Material Used on Reformed Mine Sites for Revegetation
	3
1.4	Aims of the Study
	4
1.5	Terminology
	5
CHAPTER 2	REVIEW OF THE LITERATURE
	7
2.1	The Rehabilitation Process
	7
2.1.1	Site Evaluation
	7
2.1.2	Recontouring
	9
2.1.3	Methods of Stabilizing Mine Wastes
	9
2.2	Revegetation
	10
2.2.1	Factors Affecting the Natural Colonization of Mine Sites by Trees
	10
2.2.2	Natural Colonization of Mined Areas Within the Hunter Valley
	11
2.2.3	The Use of Trees in Rehabilitation
	12
2.2.4	Comparing Tree Establishment Techniques
	13
2.2.5	Direct Seeding
	14

TABLE OF CONTENTS (cont.)

		Page
2.3	Establishment of Native Flora on Mined Land	15
2.3.1	The Effect of Mining on Overburden Strata	16
2.3.2	Differences in Soil Chemical Conditions Following Overburden Disturbance and Their Effect on Plant Growth	17
2.3.2.1	Salinity	17
2.3.2.1.1	The Effects of Salinity on Germination	18
2.3.2.1.2	The Effects of Salinity on Plant Growth	20
2.3.2.2	The Effects of Sodidity on Plant Establishment	22
2.3.2.3	The Effects of pH on Plant Establishment	25
2.3.2.4	The Effect of Nutrient Deficiency on Plant Establishment	26
2.3.2.5	Amelioration of Chemical Limitations	33
2.3.3	Differences in Soil Physical Conditions Following Overburden Disturbance and Their Effect on Plant Establishment	35
2.3.3.1	Compaction	36
2.3.3.2	Structural Instability and Texture	37
2.3.3.3	Water Relations	38
2.3.3.4	Surface Crusting	41
2.3.3.5	Erosion	42
2.3.3.6	Colour, Albedo and Temperature	43
2.3.3.7	Amelioration of Physical Limitations	45
2.3.4	Weathering of Spoil	47
2.4	Foliar Nutrient Analysis	49
2.5	Weed Competition	51
2.5.1	Pre-Emergent Herbicides	52

TABLE OF CONTENTS (cont.)

		Page
CHAPTER 3	DESCRIPTION OF HUNTER VALLEY MINE SITES	55
3.1	General Description of Hunter Valley Conditions	55
3.1.1	Location	55
3.1.2.	Climate	55
3.1.2.1	Rainfall	57
3.1.2.2	Temperature	60
3.1.3	Topography, Soils and Vegetation	60
3.1.4	Geology	64
3.2	Description of Conditions at Hunter Valley No. 1 Mine	65
3.2.1.	Location	65
3.2.2	Climate	65
3.2.2.1	Rainfall	65
3.2.2.2	Temperature	67
3.2.2.3	Evaporation	67
3.2.3	Topography, Soils and Vegetation	70
3.2.4	Geology	71
CHAPTER 4	MATERIALS AND METHODS	72
4.1	Introduction	72
4.2	Possible Sources of Variation Between Glasshouse and Field Experiments	72
4.3	General Materials and Methods	74
4.3.1	Glasshouse Experiments	74
4.3.1.1	Nature of the Experiments	74
4.3.1.2	Potting Materials	76
4.3.1.3	Plant Material	76
4.3.1.4	Fertilizer, Watering and Randomization	78

TABLE OF CONTENTS (cont.)

	Page
4.3.1.5	Monitoring, Harvesting and Analysis 78
4.3.2	Field Experiments 79
4.3.2.1	Location and Description 79
4.3.2.2	Experimental Design 81
4.3.2.3	Site Selection and Details 81
4.3.2.4	Plant Material 81
4.3.2.5	Fertilizer 82
4.3.2.6	Site Preparation 82
4.3.2.7	Maintenance 82
4.3.2.8	Monitoring and Analysis 82
4.4	Specific Materials and Methods 85
4.4.1	Glasshouse Experiments 85
4.4.1.1	Glasshouse Experiment 1 - Effect of Nitrogen, Phosphorus and Substrate on Germination and Early Growth 85
4.4.1.2	Glasshouse Experiment 2 - Effect of Soil Amendments on Germination and Early Growth 86
4.4.1.3	Glasshouse Experiment 3 - Effect of Different Watering Regimes on the Physical and Chemical Characteristics of Substrates 88
4.4.1.4	Glasshouse Experiment 4 - Effect of Omitting Essential Nutrients - C.S.P. Lemington Colliery 90
4.4.1.5	Glasshouse Experiment 5 - Effect of Omitting Essential Nutrients - Hunter Valley No. 1 Colliery 91
4.4.1.6	Glasshouse Experiment 6 - Effect of Nitrogen, Phosphorus and Substrate on Early Seedling Growth 91

TABLE OF CONTENTS (cont.)

		Page
4.4.1.7	Glasshouse Experiment 7 - Effect of Two Pre-emergent Herbicides on Germination and Early Growth	92
4.4.2	Field Experiments	94
4.4.2.1	Field Experiment 1 - Site Preparation/ Mulch Experiment	94
4.4.2.2	Field Experiment 2 - Soil Amendment Experiment	97
4.4.2.3	Field Experiment 3 - Fertilizer Rate/ Pellet Experiment	97
4.4.2.4	Field Experiment 4 - Grass Competition Herbicide Experiment	98
4.4.2.5	Field Experiment 5 - Sowing Time Experiment	100
4.4.2.6	Field Experiment 6 - Pre-emergent Herbicide Experiment	101
4.4.2.7	Field Experiment 7 - Japanese Millet Competition Experiment	103
4.5	Broadacre Field Trials	104
4.5.1	Broadacre Field Trial 1 - Bloomfield Colliery (Lower Hunter Valley)	104
4.5.2	Broadacre Field Trial 2 - C.S.R. Lemington Colliery (Upper Hunter Valley)	105
4.6	Physical and Chemical Properties of Substrates	106
4.6.1	Chemical Analyses	106
4.6.2	Physical Analyses	107
4.7	Foliar Analysis	109
CHAPTER 5	PHYSICAL AND CHEMICAL PROPERTIES OF SUBSTRATES	110
5.1	Introduction	110
5.2	Results and Discussion	111

TABLE OF CONTENTS (cont.)

		Page
5.2.1	Chemical Analyses	111
5.2.2	Physical Analyses	114
5.2.3	Implications for Rehabilitation	122
CHAPTER 6	FACTORS AFFECTING GERMINATION AND EARLY GROWTH - GLASSHOUSE EXPERIMENTS - RESULTS AND DISCUSSION	124
6.1	Introduction	124
6.2	Glasshouse Experiment 1. Effect of Nitrogen, Phosphorus and Substrate Characteristics on Germination and Early Growth	124
6.2.1	Objective	125
6.2.2	Results	125
6.2.3	Discussion	138
6.2.4	Summary	142
6.3	Glasshouse Experiment 2. Effect of Soil Amendments on Germination, Early Growth and Survival	143
6.3.1	Introduction and Objective	143
6.3.2	Results	143
6.3.3	Discussion	149
6.3.4	Summary	151
6.4	Glasshouse Experiment 3. Effect of Different Watering Regimes on the Physical and Chemical Characteristics of Substrates	151
6.4.1	Introduction	151
6.4.2	Objective	152
6.4.3	Results	152
6.4.4	Discussion	162
6.4.5	Summary	168

TABLE OF CONTENTS (cont.)

		Page
6.5	Glasshouse Experiment 4. Nutrient Omission Experiment C.S.R. Lemington Colliery	168
6.5.1	Introduction	168
6.5.2	Objective	169
6.5.3	Results	169
6.5.4	Discussion	176
6.5.5	Summary	178
6.6	Glasshouse Experiment 5. Nutrient Omission Experiment. Hunter Valley No. 1 Colliery	179
6.6.1	Introduction	179
6.6.2	Objective	179
6.6.3	Results	179
6.6.4	Discussion	185
6.6.5	Summary	188
6.7	Glasshouse Experiment 6. Effect of Nitrogen and Phosphorus on Two Species Grown on Three Substrates from C.S.R. Lemington Mine	188
6.7.1	Introduction	188
6.7.2	Objective	189
6.7.3	Results	189
6.7.4	Discussion	199
6.7.5	Summary	200
	(See section 8.2 for Glasshouse Experiment 7)	
CHAPTER 7	FIELD EXPERIMENTS AND BROADACRE FIELD TRIALS	202
7.1	General Introduction and Objectives	202
7.2	Field Experiment 1. Effect of Site Preparation and Mulch	202
7.2.1	Introduction	202
7.2.2	Objective	203
7.2.3	Results	203
7.2.4	Discussion	208

TABLE OF CONTENTS (cont.)

	Page
7.2.5	Summary 212
7.3	Field Experiment 2. Effect of Soil Amendments 212
7.3.1	Introduction 212
7.3.2	Objective 213
7.3.3	Results 213
7.3.4	Discussion 213
7.3.5	Summary 215
7.4	Field Experiment 3. Effect of Fertilizer Applied in Loose and Pelletized Form 215
7.4.1	Introduction 215
7.4.2	Objectives 216
7.4.3	Results 216
7.4.4	Discussion 218
7.4.5	Summary 223
7.5	Field Experiment 4. Effect of Herbicide on Grass Competition 223
7.5.1	Introduction 223
7.5.2	Objective 223
7.5.3	Results 224
7.5.4	Discussion 224
7.5.5	Summary 226
7.6	Field Experiment 5. Effect of Month of Sowing 226
7.6.1	Introduction 226
7.6.2	Objective 227
7.6.3	Results 227
7.6.4	Discussion 230
7.6.5	Summary 233
7.7	Field Experiment 7. Japanese Millet Competition Experiment 233
7.7.1	Introduction 233
7.7.2	Objective 234
7.7.3	Results 234
7.7.4	Discussion 237

TABLE OF CONTENTS (cont.)

		Page
7.7.5	Summary	241
7.8	Broadacre Field Trials	242
7.8.1	Introduction	242
7.8.2	Broadacre Field Trial 1. Bloomfield	
	Colliery	242
7.8.2.1	Objectives	242
7.8.2.2	Results	242
7.8.2.3	Discussion	244
7.8.3	Broadacre Field Trial 2. C.S.R. Lemington	
	Colliery	247
7.8.3.1	Objective	247
7.8.3.2	Results	247
7.8.3.3	Discussion	250
 CHAPTER 8	 EFFECT OF PRE-EMERGENT HERBICIDES ON GERMINATION AND EARLY GROWTH	 253
8.1	Introduction	253
8.2	Glasshouse Experiment 7. Effect of Two Pre-Emergent Herbicides on Germination and Early Growth	253
8.2.1	Objective	253
8.2.2	Results	253
8.2.3	Discussion	260
8.2.4	Summary	261
8.3	Field Experiment 6. Effect of Two Pre-Emergent Herbicides on the Growth of Planted Seedlings	261
8.3.1	Introduction	262
8.3.2	Objective	262
8.3.3	Results	262
8.3.4	Discussion	263
8.3.5	Summary	264

TABLE OF CONTENTS (cont.)

		Page
CHAPTER 9	GENERAL DISCUSSION AND CONCLUSIONS	265
9.1	Glasshouse Experiments	265
9.2	Field Experiments and Broadacre Field Trials	273
9.3	Further Research	289
ACKNOWLEDGEMENTS		291
REFERENCES		293
APPENDICES		
APPENDIX 1	General soil profile descriptions for Hunter Valley No. 1 mine.	317
APPENDIX 2	F values for glasshouse and field experiments.	319

LIST OF TABLES

	Page
Table 2.1 Tolerance of crops to exchangeable sodium percentage (ESP) of soils or sodium adsorption ratio (SAR) of irrigation water.	23
Table 2.2 Optimum germination temperatures of savannah woodland species native to the upper Hunter Valley, N.S.W.	44
Table 3.1 Summary of long-term rainfall characteristics for Jerrys Plains and East Maitland.	58
Table 3.2 Summary of long-term temperature characteristics for Jerrys Plains and East Maitland.	61
Table 3.3 Rainfall data for Hunter Valley No. 1 Mine (Upper Hunter Valley) for duration of the study.	66
Table 3.4 Temperature data for Hunter Valley No. 1 Mine (Upper Hunter Valley) for duration of the study.	68
Table 3.5 Evaporation data for Hunter Valley No. 1 Mine.	69
Table 4.1 Description of glasshouse experiments together with mean day-time and night-time glasshouse temperatures, source of materials and duration of each experiment.	75

LIST OF TABLES (cont.)

	Page
Table 4.2 Field sowing rates and general seed viability data for native species used in glasshouse and field experiments and broadacre field trials.	77
Table 4.3 Location and description of field experiments and broadacre field trials.	80
Table 5.1 Chemical characteristics of substrates used in glasshouse and field experiments and broadacre field trials.	112
Table 5.2 Physical characteristics of substrates used in glasshouse and field experiments and broadacre field trials.	115
Table 6.1 Effect of three substrates from Hunter Valley No. 1 Colliery on germination per cent and germination energy for <i>E. maculata</i> and <i>C. glauca</i> .	126
Table 6.2 Effect of N and substrate on the germination per cent of <i>E. maculata</i> and <i>C. glauca</i> .	127
Table 6.3 Effect of P on the germination per cent of <i>E. maculata</i> and <i>C. glauca</i> .	128
Table 6.4 Effect of P and substrate on the germination energy of <i>E. maculata</i> and <i>C. glauca</i> .	130

LIST OF TABLES (cont.)

	Page
Table 6.5 Effect of substrate on total plant dry weight, root/shoot ratio and total root and total shoot dry weights for <i>E. maculata</i> and <i>C. glauca</i> growing on three substrates from Hunter Valley No. 1 Colliery.	131
Table 6.6 Effect of N and P on the total dry weight of <i>E. maculata</i> and <i>C. glauca</i> .	134
Table 6.7 Effect of N and P on root/shoot ratio for <i>E. maculata</i> and <i>C. glauca</i> .	136
Table 6.8 Levels of nutrients in the foliage of <i>E. maculata</i> seedlings grown in three substrates from Hunter Valley No. 1 Colliery, 98 days after sowing.	137
Table 6.9 Effect of four soil amendments on germination energy.	145
Table 6.10 Effect of four soil amendments on total plant dry weight.	146
Table 6.11 Effect of four soil amendments on the average plant dry weight of <i>E. maculata</i> and <i>C. glauca</i> .	147
Table 6.12 Effect of four soil amendments on average plant dry weight for three substrates from Hunter Valley No. 1 Colliery.	148

LIST OF TABLES (cont.)

	Page
Table 6.13 Particle size analysis of the surface 5 mm before and after wetting for two watering regimes and three substrates from Hunter Valley No. 1 Colliery.	155
Table 6.14 Effect of two substrates from C.S.R. Lemington Colliery on survival per cent of <i>E. maculata</i> and <i>C. glauca</i> .	170
Table 6.15 Effect of nutrient omission on the total dry weight of <i>E. maculata</i> and <i>C. glauca</i> for two substrates from C.S.R. Lemington Colliery.	171
Table 6.16 Levels of important nutrients in the foliage of <i>E. maculata</i> and <i>C. glauca</i> seedlings grown in two substrates from C.S.R. Lemington Colliery.	174
Table 6.17 Effect of nutrient omission on the total dry weight of <i>E. maculata</i> seedlings grown in three substrates from Hunter Valley No. 1 Colliery.	181
Table 6.18 Effect of nutrient omission on the root/ shoot ratio of <i>E. maculata</i> grown in three substrates from Hunter Valley No. 1 mine.	184
Table 6.19 Effect of three substrates from C.S.R. Lemington Colliery on the total dry weight of <i>E. maculata</i> and <i>C. glauca</i> .	190

LIST OF TABLES (cont.)

	Page
Table 6.20 Effect of three substrates from C.S.R. Lemington Colliery on the root/shoot ratio of <i>E. maculata</i> and <i>C. glauca</i> .	191
Table 6.21 Effect of substrate and P on the total root dry weight of <i>E. maculata</i> and <i>C. glauca</i> .	191
Table 7.1 Effect of three substrates at Hunter Valley No. 1 Mine on germination per cent, germination energy and the angular transformation (arcsin) of survival per cent two years after sowing.	204
Table 7.2 Effect of site preparation and mulch treatments on germination per cent, for combined substrates at Hunter Valley No. 1 Mine two years after sowing.	205
Table 7.3 Germination per cent, germination energy, survival per cent, average height and average basal area for five native tree species two years after sowing.	206
Table 7.4 Effect of three substrates at Hunter Valley No. 1 Mine on germination per cent, germination energy, survival per cent, average height and average basal area two years after sowing.	214
Table 7.5 Effect of fertilizer rate and three substrates at Hunter Valley No. 1 Colliery on transformed survival per cent two years after sowing.	217

LIST OF TABLES (cont.)

	Page
Table 7.6 Effect of method of fertilizer application and fertilizer rate on transformed survival per cent two years after sowing.	219
Table 7.7 Effect of three substrates at Hunter Valley No. 1 Colliery and fertilizer rate on germination per cent two years after sowing.	220
Table 7.8 Average spoil temperature, gravimetric moisture content and per cent ground cover, measured for five different pasture swards on Topdressing (1) at Hunter Valley No. 1 Mine.	225
Table 7.9 Effect of month of sowing on germination per cent and germination energy at Hunter Valley No. 1 Mine	228
Table 7.10 Effect of three substrates at Hunter Valley No. 1 Mine on average basal area and average height.	229
Table 7.11 Average monthly substrate moisture percentages at Hunter Valley No. 1 Mine.	231
Table 7.12 Effect of five rates of Japanese Millet on germination per cent and germination energy of native tree species for two substrates at Bloomfield Colliery in the lower Hunter Valley.	235
Table 7.13 Effect of two substrates at Bloomfield Colliery on germination per cent, germination energy and survival per cent.	236

LIST OF TABLES (cont.)

	Page
Table 7.14 Effect of two substrates at Bloomfield Colliery on stocking rate, composition per cent, average height (m), germination and survival per cent for five native tree species 12 months after sowing or planting.	245
Table 7.15 Effect of two substrates at C.S.R Lemington Colliery on stocking rate, composition per cent, average height (m) and average basal area (cm ²) for seven native tree species 12 months after sowing.	249
Table 8.1 Effect of the pre-emergent herbicide Diphenamid applied at 0 and 7 kg active ingredient ha ⁻¹ on foliar N and P concentrations and on the N:P ratio for <i>E. maculata</i> and <i>A. saligna</i> seedlings 169 days after sowing and treatment.	259

LIST OF FIGURES

	Page
Figure 2.1 Approximate amounts of available and unavailable water held by soil of different textures.	39
Figure 3.1 Locality map of Hunter Valley showing trial collieries and major coal measures.	56
Figure 3.2 Isohyets of mean annual rainfall distribution for study area.	59
Figure 5.1 Effect of rainfall on gravimetric moisture content for three substrates from Hunter Valley No. 1 Colliery.	116
Figure 5.2 Effect of rainfall on gravimetric moisture content for two substrates from Bloomfield Colliery.	117
Figure 5.3 Mean monthly maximum, minimum and mean temperatures at the spoil surface under shade for a 12 month period at Hunter Valley No. 1 Colliery.	119
Figure 5.4 Temperature variation over a five hour period at Hunter Valley No. 1 Colliery on the 30th January, 1987.	121
Figure 6.1 Effect of substrate, time and watering regime on surface crust strength for three substrates from Hunter Valley No. 1 Colliery.	153

LIST OF FIGURES (cont.)

	Page
Figure 6.2 Effect of substrate and time on pH for three substrates from Hunter Valley No. 1 Colliery.	157
Figure 6.3 Effect of watering regime and time on pH.	158
Figure 6.4 Effect of watering regime and time on salinity.	160
Figure 6.5 Effect of substrate and time on salinity.	161
Figure 6.6 Effect of watering regime and time on gravimetric moisture content for three substrates from Hunter Valley No. 1 Colliery.	163
Figure 6.7 Effect of P applied as $\text{NaH}_2\text{PO}_4 \cdot 2\text{H}_2\text{O}$ on total plant dry weight of <i>E. maculata</i> for three substrates from C.S.R. Lemington Colliery.	195
Figure 6.8 Effect of P applied as $\text{NaH}_2\text{PO}_4 \cdot 2\text{H}_2\text{O}$ on plant dry weight of <i>C. glauca</i> for three substrates from C.S.R. Lemington Colliery.	196
Figure 6.9 Effect of N applied as NH_4NO_3 on total plant dry weight of <i>E. maculata</i> for three substrates from C.S.R. Lemington Colliery.	197

LIST OF FIGURES (cont.)

	Page
Figure 6.10 Effect of N applied as NH_4NO_3 on total plant dry weight of <i>C. glauca</i> for three substrates from C.S.R. Lemington Colliery	198
Figure 7.1 Temperature fluctuations at the surface and at 2cm depth for three mulches on Sandstone (2) at Hunter Valley No. 1 Colliery during the period 10 am to 1 pm on the 20th November, 1985.	207
Figure 7.2 Effect of increasing sowing rates of Japanese millet on average height of native tree species 12 months after sowing.	238
Figure 7.3 Spoil gravimetric moisture contents measured over a 15 day period between 29th May and 12th June 1986 for five rates of Japanese millet on Topdressing (19) at Bloomfield Colliery (lower Hunter Valley).	239
Figure 8.1 Effect of herbicide on the germination per cent of three native tree species sown into Topdressing (16) from Ravensworth No. 2 Colliery.	254
Figure 8.2 Effect of herbicide on the survival per cent of three native tree species sown into Topdressing (16) from Ravensworth No. 2 Colliery.	256

LIST OF FIGURES (cont.)

	Page
Figure 8.3 Effect of herbicide on the total shoot dry weight of three native species sown into Topdressing (16) from Ravensworth No. 2 Colliery.	257

LIST OF PLATES

	Page
Plate 4.1 Deep ripping treatment in field experiment 1 on Sandstone (2) at Hunter Valley No. 1 Mine.	95
Plate 4.2 Cultivation treatment in field experiment 1 on Sandstone (2) at Hunter Valley No. 1 Mine.	95
Plate 4.3 Straw mulch treatment in field experiment 1 on Sandstone (2) at Hunter Valley No. 1 Mine.	96
Plate 4.4 Chitter mulch treatment in field experiment 1 on Sandstone (2) at Hunter Valley No. 1 Mine.	96
Plate 6.1 The response of <i>E. maculata</i> seedlings grown on Topdressing (1) from Hunter Valley No. 1 Mine to applied N and P.	132
Plate 6.2 The response of <i>E. maculata</i> seedlings grown on Sandstone (2) from Hunter Valley No. 1 Mine to applied N and P.	132
Plate 6.3 The response of <i>E. maculata</i> seedlings grown on Shale (3) from Hunter Valley No. 1 Mine to applied N and P.	132
Plate 6.4 The response of <i>E. maculata</i> grown in three substrates from Hunter Valley No. 1 Mine to "All" nutrients.	182

LIST OF PLATES (cont.)

	Page
Plate 6.5 The response of <i>E. maculata</i> grown in three substrates from Hunter Valley No. 1 Mine to minus N.	182
Plate 6.6 The response of <i>E. maculata</i> grown in three substrates from Hunter Valley No. 1 Mine to minus P.	183
Plate 6.7 The response of <i>E. maculata</i> grown in three substrates from Hunter Valley No. 1 Mine to "No" nutrients.	183
Plate 6.8 The response of <i>E. maculata</i> grown on Topdressing (13) from C.S.R. Lemington Mine to applied N and P.	193
Plate 6.9 The response of <i>E. maculata</i> grown on Sandstone (14) from C.S.R. Lemington Mine to applied N and P.	193
Plate 6.10 The response of <i>E. maculata</i> grown on Shale (15) from C.S.R. Lemington Mine to applied N and P.	193
Plate 7.1 Directly sown native tree species growing on Topdressing (19) at Bloomfield Colliery 22 months after sowing.	243

LIST OF PLATES (cont.)

	Page
Plate 7.2 Directly sown native tree species growing on Overburden (20) at Bloomfield Colliery 22 months after sowing.	243
Plate 7.3 Directly sown native tree species growing on Topdressing (13) at C.S.R. Lemington Mine 12 months after sowing.	248
Plate 7.4 Directly sown native tree species growing on Overburden (14) at C.S.R. Lemington Mine 12 months after sowing.	248
Plate 8.1 Effect of two pre-emergent herbicides, Surflan and Diphenamid, each at two rates, on directly sown <i>A. saligna</i> on Topdressing (16) from Ravensworth No. 2 Mine 169 days after sowing.	258
Plate 8.2 Effect of two pre-emergent herbicides, Surflan and Diphenamid, each at two rates, on directly sown <i>E. maculata</i> on Topdressing (16) from Ravensworth No. 2 Mine 169 days after sowing.	258

LIST OF PLATES (cont.)

	Page
Plate 9.1 Root growth of five year old <i>E. punctata</i> planted into spoil material at Drayton Mine.	278
Plate 9.2 Root growth of five year old <i>E. cladocalyx</i> planted into spoil material at Drayton Mine.	279