Growth and nutritional responses of *Eucalyptus* and *Corymbia* species during plantation establishment using effluent irrigation and organic compost on mine overburden in the Hunter Valley, NSW

Angela Cummings

A thesis submitted for the Degree of Doctor of Philosophy at the University of New England

June 2007

Ecosystem Management
University of New England
Armidale, NSW
Australia

DECLARATION

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

I certify that any help received in preparing this thesis, and all sources used, have been acknowledged in this thesis.

Angela Cummings

ABSTRACT

In an attempt to make the communities which have developed in the Hunter Valley sustainable in the long-term, local government, community groups, regulators and mining operators want to ensure that the long-term legacy of mining in the region is minimised and that potential benefits are maximised. Rehabilitation efforts are focused on activities that will benefit the community after the extraction process has been completed. Regional planning has identified that commercial native forest plantations are considered as an opportunity for mine rehabilitation. While current rates of tree growth are not considered to be commercially viable, practical solutions are available to reduce current limitations and improve the viability of overburden stockpiles for production of forests with enhanced growth rates. In 1999, Muswellbrook Shire Council and the University of New England formed a partnership to research the feasibility of establishing commercial forests on coal mine overburden using effluent irrigation and organic compost, at a site in the Upper Hunter Valley. This thesis examines the effectiveness of using these techniques to enhance the establishment of *Corymbia maculata*, and seven *Eucalyptus* species, on coal mine overburden.

The establishment of *C. maculata* was examined in an irrigation and compost experiment. Response variables, including tree survival, height, diameter, volume, above ground biomass production, stem form and tree health, were sampled at intervals up to 36 months post-planting. Substrate, tree and weed nutrient status was also assessed at 12 and 24 months. Nutrient use efficiencies and nutrient budgets were developed for *C. maculata* in relation to different treatments which included irrigation and compost ($IC_{IRR+COMP}$), irrigation ($I_{IRRIGATION}$), compost ($C_{COMPOST}$) and control ($N_{CONTROL}$).

After 36 months, survival, height and diameter of *C. maculata* was not influenced by treatment. Survival ranged from 39 % ($C_{COMPOST}$) to 68 % ($I_{IRRIGATION}$). Heights and diameters ranged from an average of 2.7 to 3.5 m, and 41 mm to 56 mm, respectively. Above ground biomass production was significantly greater for $I_{IRRIGATION}$ in comparison to other treatments and production was ten times greater than for $N_{CONTROL}$. The $IC_{IRR+COMP}$ treatment resulted in healthier, better formed trees. Based on the results of this experiment $IC_{IRR+COMP}$ and $I_{IRRIGATION}$ were recommended for future use. $C_{COMPOST}$ can also provide a benefit if effluent irrigation is not available but future use of $N_{CONTROL}$ was not recommended.

A positive effect of treatment application on substrate quality and tree growth was expected given the initial poor qualities of the overburden. Nitrogen (total) increases in the substrate material were associated with the addition of compost, with greatest concentrations of nitrate present in $IC_{IRR+COMP}$, highlighting the additional benefits of providing sufficient water with nutrients to enhance availability. Nutrient concentrations in trees did not differ between treatments, and were mostly within normal ranges for young plantation trees of *C. maculata*. Despite intense competition from weeds, significant

differences between treatments for the accumulation of N and K in trees were evident, highlighting the benefits of treatments for enhanced nutrient absorption. At 24 months, nitrogen accumulation in wood tissue was greatest for $I_{IRRIGATION}$ (2.2 kg ha^{-1}), which was more than double that recorded for $IC_{IRR+COMP}$ (0.9 kg ha^{-1}), $C_{COMPOST}$ (0.6 kg ha^{-1}) and $N_{CONTROL}$ (0.5 kg ha^{-1}). Trees growing under $I_{IRRIGATION}$ were commonly the most efficient user of nutrients. Due to lower nutrient application which enabled a high renovation capacity, $I_{IRRIGATION}$ was a lower risk treatment and was therefore recommended for future use. The nutrient budgets developed for each treatment largely reflected differences in nutrient inputs, with little evidence that effluent irrigation and compost allocation were unsustainable.

Given the natural distribution patterns of eucalypts with respect to soil types and climatic conditions, it was anticipated that growth rates of other species could also be enhanced with effluent irrigation and compost application. A species selection experiment was established using the $IC_{IRR+COMP}$ treatment to compare growth and nutrition variables of *C. maculata*, *Eucalyptus grandis*, *Eucalyptus nitens*, *Eucalyptus badgensis*, *Eucalyptus saligna*, *Eucalyptus botryoides*, *Eucalyptus dunnii* and *Eucalyptus punctata*.

After 36 months survival rates for *E. dunnii* (84 %), *E. botryoides* (86 %), *E. punctata* (85 %), *E. grandis* (83 %) and *E. saligna* (74 %) were significantly greater than the remaining species. Mean height was greatest for *E. botryoides* (563.9 cm) but not significantly greater than *E. dunnii* (541.9 cm), *E. badgensis* (540.0 cm), *E. grandis* (500.5 cm) and *E. punctata* (468.7 cm). Above ground biomass production was greatest for *E. grandis* (10,746 kg ha^{-1}), *E. botryoides* (8,856 kg ha^{-1}) and *E. badgensis* (8,141 kg ha^{-1}). *Eucalyptus botryoides* and *E. badgensis* acquired the most volume in this experiment, closely followed by *E. grandis*, *E. dunnii* and *E. punctata*, demonstrating that some of these are species are capable of reaching increments of 16 m^3 ha^{-1} $year^{-1}$ (considered suitable for commercial forestry). Assessment of stem form and tree health enabled further comparison of species. After consideration of all measurement variables, *E. grandis*, *E. botryoides* and *E. badgensis* were highly recommended for future use displaying comparably good growth rates and reasonable form and health characteristics. Future use of *C. maculata* and *E. nitens* was not recommended for commercial forestry purposes. Mid-range species, *E. dunnii*, *E. punctata* and *E. saligna*, listed in order of preference, could also be suitable depending on circumstances or the number of species required.

Nutrient accumulations were directly and positively related to growth and significant differences between species were found for wood and foliage, for all nutrients. Higher accumulation of nutrients for *E. botryoides*, compared to some other species, further supported its high ranking for growth characteristics. For nutrient use efficiency, *E. badgensis* and *E. punctata* were the most efficient users of nutrients, compared to other species. Nutrient budgets provided further insight into species performances and renovation capacity. All species plots renovated the entire amounts of nitrogen and

phosphorus applied but there were differences in the amounts that were renovated by the plant components. Excellent renovation capacity recorded for the plant biomass in *E. botryoides* plots was evident in all nutrient budgets, and therefore this species was recommended as the preferred species for this circumstance, based on the results of this experiment. The ability of *E. botryoides* to rapidly produce biomass and accumulate nutrients reduced the quantities lost to subsoil.

The main limitations to the experiments were the short time frame over which plantation establishment was monitored and the extensive development of weed biomass. Weed growth considerably reduced the performance of all treatments and species, affecting growth and nutritional responses. There was some evidence that organic compost enhanced weed growth. Despite these limitations, it became apparent that establishment of commercially viable plantations on coal mine overburden is possible using, effluent irrigation and organic compost. If commercially viable plantations can be established on overburden using recycled waste products, further incentives for establishing a local forest industry exist. Establishment of a forest industry will add production diversity to the landscape and will enhance resilience of local communities to changes in the economic environment. Further, correctly managed re-use of effluent in terrestrial systems will enhance local water quality conditions.

Further monitoring of these experiments should to be undertaken, and recommendations for future research have been provided. Based on the results of both experiments, the most sustainable and likely commercial management option for establishment of plantations on overburden is to use effluent irrigation with *E. botryoides*. Other treatments and species were also suitable as per the recommendations made. In all circumstances, and particularly if organic compost is used, weed control efforts should be well planned and consistently applied in order to achieve maximum growth.

TABLE OF CONTENTS

DECLARATION 2
ABSTRACT 3
CHAPTER 1 INTRODUCTION 10
1.1 BACKGROUND AND LITERATURE REVIEW 10
1.1.1 Introduction 10
1.1.2 Mine Site Rehabilitation 11
Sustainability Issues 11
Mining Rehabilitation in the Hunter Valley – History and Limitations 13
The Emerging Role of Trees and Commercial Forestry Options 15
1.1.3 Overcoming Limitations to Rehabilitation and Commercial Forestry 19
Effluent Irrigation 19
Application of Organic Compost 23
1.1.4 Conclusion 24
1.2 MUSWELLBROOK SHIRE COUNCIL OBJECTIVES 25
1.3 RESEARCH OBJECTIVES 26
CHAPTER 2 SITE DESCRIPTION, EXPERIMENTAL DESIGN AND METHODOLOGY 28
2.1 DESCRIPTION OF STUDY SITE 28
2.1.1 Mining and the Hunter Valley 28
2.1.2 Climate 28
2.1.3 Geology and Slope Formation 28
2.1.4 Vegetation Characteristics 29
2.1.5 Groundwater and Hydrology 29
2.1.6 Site Selection 29
Current Rehabilitation Practices 29
Experimental Site 31
2.2 EXPERIMENTAL DESIGN, METHODOLOGY AND MONITORING PROGRAM. 31
2.2.1 Introduction 31
2.2.2 Trial Establishment 31
2.2.3 Species Selection 32
2.2.4 Rainfall and Evaporation 32
2.2.5 Compost Application 34
2.2.6 Effluent Irrigation 36
Irrigation Scheduling 37
2.2.7 Weed Control 40
2.2.8 Introduction to PMPs and DSPs 40
2.2.9 Monitoring Program 40
CHAPTER 3 IRRIGATION AND COMPOST EXPERIMENT - PART 1 SURVIVAL, GROWTH, BIOMASS, FORM AND HEALTH 44
3.1 INTRODUCTION 44
3.2 EXPERIMENTAL DESIGN AND METHODS 46
3.2.1 Experimental Design 46
3.2.2 Methods 46
Effluent Irrigation and Compost Application 46
Measurement Techniques 48
Data Management and Statistical Analysis 53
3.3 RESULTS 55
3.3.1 Survival 55

3.3.2 Tree Growth 56
Height 56
Diameter 56
Stem Volume 60
3.3.3 Above-Ground Biomass Production 60
Weeds 60
Trees (Total Biomass) 61
Trees (Biomass Components and Distribution) 61
3.3.4 Stem Form 64
3.3.5 Tree Health 67
3.3.6 Performance Rankings 68
3.4 DISCUSSION 69
3.4.1 Survival 69
3.4.2 Height and Diameter 70
3.4.3 MAI and Volume 72
3.4.4 Weeds (Above-Ground Biomass) 73
3.4.5 Trees (Above-Ground Biomass) 74
Distribution 79
3.4.6 Stem Form and Tree Health 81
3.4.7 Performance Rankings 81
3.5 CONCLUSION 82
CHAPTER 4 IRRIGATION AND COMPOST EXPERIMENT - PART 2 NUTRITION 84
4.1 INTRODUCTION 84
4.2 EXPERIMENTAL DESIGN AND METHODS 86
4.2.1 Experimental Design 86
4.2.2 Methods 86
Effluent Irrigation and Compost Application 86
Measurement Techniques 86
Data Management and Statistical Analysis 89
4.3 RESULTS 89
4.3.1 Nutrient Concentration 89
Substrate 90
Trees 95
Weeds 95
4.3.2 Nutrient Accumulation 96
Substrate 96
Trees 96
Weeds 97
4.3.3 Nutrient Distribution 99
4.3.4 Nutrient Use Efficiency 101
4.3.5 Nutrient Budget 101
4.4 DISCUSSION 104
4.4.1 Nutrient Concentration 104
Substrate 104
Trees and Weeds 109
4.4.2 Nutrient Accumulation 111
4.4.3 Nutrient Distribution 116
4.4.4 Nutrient Use Efficiency 116
4.4.5 Nutrient Budget 120
4.5 CONCLUSION 122

CHAPTER 5 SPECIES SELECTION EXPERIMENT - PART 1 SURVIVAL, GROWTH, BIOMASS, FORM AND HEALTH 123
5.1 INTRODUCTION 123
5.2 EXPERIMENTAL DESIGN AND METHODS 124
5.2.1 Experimental Design 124
5.2.2 Methods 126
Effluent Irrigation and Compost Application 126
Measurement Techniques 126
Data Management and Statistical Analysis 126
5.3 RESULTS 126
5.3.1 Survival 126
5.3.2 Tree Growth 127
Height 127
Top Height 128
Diameter 128
Top Diameter 128
Volume 130
5.3.3 Above-Ground Biomass Production 131
Weeds 131
Trees (Total Biomass) 131
Trees (Biomass Components and Distribution) 132
5.3.4 Stem Form 133
5.3.5 Tree Health 136
5.3.6 Performance Rankings 137
5.4 DISCUSSION 140
5.4.1 Survival 142
5.4.2 Height and Diameter 143
5.4.3 MAI and Volume 144
5.4.4 Weeds (Above-Ground Biomass) 145
5.4.5 Trees (Above-Ground Biomass) 146
5.4.6 Stem Form and Tree Health 148
5.4.7 Performance Rankings 150
5.5 CONCLUSION 152
CHAPTER 6 SPECIES SELECTION EXPERIMENT - PART 2 NUTRITION 153
6.1 INTRODUCTION 153
6.2 EXPERIMENTAL DESIGN AND METHODS 154
6.2.1 Experimental Design 154
6.2.2 Methods 154
6.3 RESULTS 154
6.3.1 Nutrient Concentration 154
Substrate 154
Trees 155
Weeds 156
6.3.2 Nutrient Accumulation 157
Trees 157
Weeds 163
6.3.3 Nutrient Distribution 167
Nitrogen and Phosphorus 167
Cations 167
6.3.4 Nutrient Use Efficiency 168

6.3.5 Nutrient Budget 173
6.4 DISCUSSION 175
6.4.1 Nutrient Concentration 175
Substrate 175
Trees 175
Weeds 177
6.4.2 Nutrient Accumulation 178
6.4.3 Nutrient Distribution 180
6.4.4 Nutrient Use Efficiency 181
6.4.5 Nutrient Budget 186
6.5 CONCLUSION 187
CHAPTER 7 SYNTHESIS 189
REFERENCES 192
APPENDICES 208
APPENDIX A 209
APPENDIX B 211
APPENDIX C 215
APPENDIX D 226
APPENDIX E 240
DEDICATION 251