Production potential of Eucalypt woodlots for bio-energy in the Winelands region of the Western Cape

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Declaration

By submitting this dissertation electronically, I declare that the entirety of the work contained therein is my own, original work, that I am the owner of the copyright thereof (unless to the extent explicitly otherwise stated) and that I have not previously in its entirety or in part submitted it for obtaining any qualification.

March 2010

Summary

The purpose of the study was to investigate the potential tree taxa that could be grown as a source of biomass in the Cape Winelands region. The trials comprises of two different aspects. The first being the estimation of potential volume, density and biomass of a pair of six year-old stands of ***E. gomphocephala*** and ***E. cladocalyx*** families at two climatically different sites within the study region. The second part of the study was the early growth assessment of alternative taxa that could be planted in the region compared to the regional mainstay ***E. cladocalyx***.

The volume of families was estimated using appropriate volume equations and using the form height were none were available. The best volume yield varied from 4.6 to 11.2 m^3 $ha^{-1}a^{-1}$, at the dry and sub-humid sites, respectively. Wood density, estimated from non-destructive samples at both sites, varied from 620 (sub-humid) to 588 kg m^{-3} (dry site). The estimated biomass production rate of the top producing families yielded 2.7 and 6.9 t $ha^{-1}a^{-1}$ at the dry and sub-humid sites, respectively. In terms of estimated biomass and survival, ***E. gomphocephala*** was more suited to the dry site, while ***E. cladocalyx*** displayed superior yield than ***E. gomphocephala*** on the sub-humid site, but not significantly so.

Early growth assessment of the trial of alternative taxa found that the hybrid ***E. grandis × camldulensis*** and ***E. grandis × urophylla*** had superior biomass indices, but were more susceptible to infestation by ***Thaumastocoris peregrinus*** and ***Gonipterus scuttelatus***.

Opsomming

Die doel van hierdie studie was om potensiële boom taksa vir gebruik as ’n bron van biomassa in die Kaapse Wynlandstreek te ondersoek. Die proewe behels twee aspekte: eerstens die beraming van die potensiële volume, digtheid en biomassa van sesjaaroue opstande met families van ***E. gomphocephala*** en ***E. cladocalyx*** by twee klimatologies verskillende groeiplekke in die studiegebied; tweedens die beoordeling van die vroeë groei van alternatiewe taksa wat in die streek geplant kan word in vergelyking met die streek se historiese staatmaker-spesie ***E. cladocalyx***.

Die volume van die families is beraam deur gebruik te maak van toepaslike volumevergelykings, en met behulp van ’n vormfaktor waar vergelykings nie beskikbaar was nie. Die volume aanwas by die droë en sub-humiede groeiplekke was onderskeidelik 4.6 en 11.2 m^{3} ha^{-1}j^{-1}. Houtdigtheid is beraam deur nie-destruktiewe monsters uit die opstand te neem. Gemiddelde digthede het varieer van 588 (sub-humied) tot 620 kg m^{-3} (droë groeiplek). Die beraamde biomassaproduksie van die top-families beloop onderskeidelik 2.7 en 6.9 t ha^{-1}j^{-1} vir die droë en sub-humiede groeiplekke. In terme van beraamde biomassa en oorlewing, is ***E. gomphocephala*** meer geskik vir droër groeiplekke , terwyl ***E. cladocalyx*** by die sub-humiede groeiplek ’n hoër opbrengs as ***E. gomphocephala*** getoon het, hoewel nie betekenisvol nie.

Beramings van die vroeë groei by die proef met alternatiewe taksa het getoon dat die basters ***E. grandis × camldulensis*** en ***E. grandis × urophylla*** hoër biomassa-indekse het, maar meer vatbaar is vir besmetting deur ***Thaumastocoris peregrinus*** en ***Gonipterus scuttelatus***.

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Dbh- diameter at breast height, 1.3m from the ground

E_p- Estimated Evaporation

GHG- Green House Gases

IPCC- International Panel on Climate Change

LCA- Life cycle analysis

MAE- Mean Annual Evaporation

MAE_p- A-pan evaporation

MAP- Mean Annual Precipitation

m.a.s.l- metres above sea level

MAT- Mean Annual Temperature

Max. Temp- Maximum Temperature

Min. Temp- Minimum Temperature

sph- Stems per hectare

UNFCC- United Nations Forum on Climate Change

Chapter 1: Introduction

1.1 Background

Green house Gasses (GHG) are believed to be the largest contributor to the climate changes that have systematically been taking place (***Blignaut et al.,*** 2005). There are a few GHG that are partially responsible for these namely N_2O and CH_4, but the main contributor to GHG world-wide is CO_2. The emission of CO_2 is mainly due to the combustion of coal that supplies 70% of South Africa's energy (***Blignaut et al.,*** 2005). Industrial processes are the largest consumer of electricity in the country (44.2%), followed by services (26.2%), residential demands (16%), mining (8%) and the agricultural sector (5%) (***Blignaut et al.***, 2005). However, the largest emitter of GHG in South Africa is the transport sector, and thus it is in this sector where the major mitigation projects are geared (***Department of Minerals and Energy***, 2007).

Carbon footprint is a measurable amount of carbon that is emitted to the atmosphere by a certain organization or individual. This encapsulates everything that we do, from the fossil fuel burnt to provide electricity, fuel consumption, to the products that we purchase. To maintain a balance between carbon sequestration and carbon emissions, calculations can be made to determine a finite amount of carbon emissions for each individual, based on the amount of CO_2 the earth can sequester. When this finite share is exceeded the effects of CO_2 and other GHG will become detrimental to the environment. Currently, the emission of GHG exceeds the amount that the earth can sequester. To counteract this, the concept of decreasing carbon footprints becomes important. If all organizations and every individual are willing to reduce the amount of carbon they emit from the earth, there will be a decrease in the effects of global warming. As will be discussed in more detail later, forestry could play a larger role in the energy industry as a whole. Not only is woody vegetation and it's biomass an alternative source of energy, it can also replace the use of steel and iron, the production of which demands a large portion of the energy consumed by the industrial sector in South Africa (***Blignaut et al.,*** 2005).

South Africa has a carbon use intensity that is 240 % more than the average usage world-wide, the highest of all developing countries considered, such as China, Brazil, Nigeria and Argentina, which are all of comparable development stages to South Africa (***Blignaut et al***., 2005). **Figure 1.1** illustrates the demand of various sources of energy. Currently renewable resources supply only 8% of the required residential energy consumption, while this sector uses 16% of the total available energy in South Africa. If renewable energy is made more available to this sector (and other sectors strongly reliant on electricity), it could contribute to the reduction of CO_2 emissions in South Africa. The Department of Minerals and Energy investigation in 2003, found the transport sector most damaging to the environment. Therefore, the national mitigation strategy focuses mainly on the use of agricultural crops to produce 10 000 GWh of energy annually by 2013 (***Department of Minerals and Energy,*** 2007). This could be achieved by enforcing a mandatory blend of bioethanol or biodiesel with fuel sources. The main crops that are considered are sugar cane and sugar beet as a source of a bioethanol blend and sunflower, canola and soya beans as a source of biofuel (***Department Minerals and Energy,*** 2007). Maize, although a good producer of biofuel, is not considered in the strategy because of the effect the competition might have on food security (***Department Minerals and Energy,*** 2007). The strategy also doesn't outline any steps to return carbon deposits to the earth. Biomass from trees are a desirable source of energy as it is comparable to other sources of biomass (i.e. bagasse and wheat), having good intrinsic material properties such as moisture content, ash content and calorific values (***McKendry,*** 2002). The downfall of the wood as a source of bioenergy is the area it requires to produce an economically viable yield (***McKendry,*** 2002). This is where trees could become very useful, because they can be used on marginal land, could possibly be used as a source of electricity and sequester large amounts of carbon (***Marland and Schlamadinger, 1997; Cook & Beyea***, 2000).

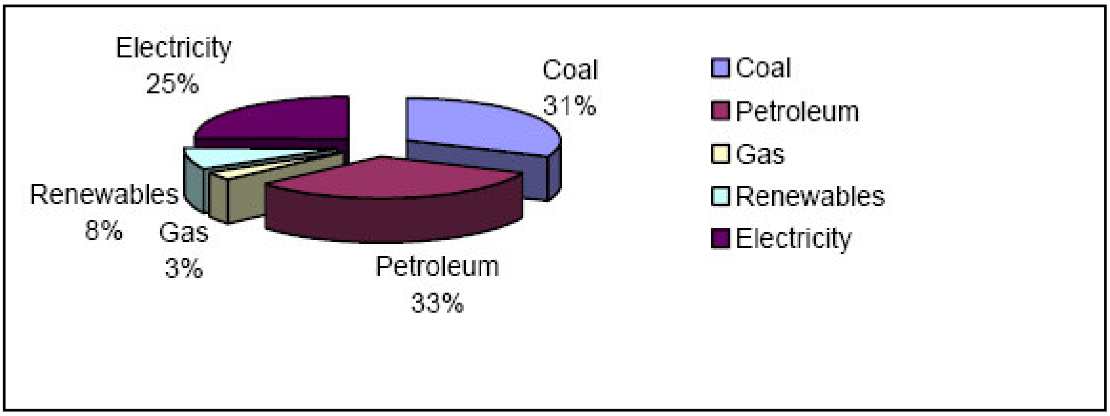

Figure 1.1*.* Share of final demand for energy by fuel type in 1998 (***Blignaut et al***, 2005)

1.2 Bioenergy from forest plantations

Bio-energy is the energy that is produced using biomass. Approximately 14% (50 exajoules) of the world's energy use is obtained from a bio-energy source (***Schlamadinger & Marland,*** 1996)***,*** of which 38% is used in developing countries. Trees can possibly reduce carbon from the atmosphere in four basic ways (***Schlamadinger & Marland,*** 1996):

- The storage of carbon in the biosphere
- The storage of carbon in forest products
- The replacing of fossil fuels by bio fuels
- The use of wood as a product instead of other products that cost more carbon to produce.

The combustion of fossil fuels has been found to be the primary producers of atmospheric CO_2. The basic concept of various trees and plants reducing the CO_2 in the atmosphere is that the solar energy is thus stored in the plant as carbohydrates, the building blocks of woody biomass (***McKendry,*** 2002).

The woody biomass in-turn is used as a form of biomass for fuel to replace or off set fossil fuels (***Schlamdinger & Marland,*** 1996). In order to efficiently use biomass as a likely alternative for energy production, a life cycle and the role that the biomass (trees) plays in the environment must be understood in order to manipulate the situation for biomass production. Typically, a Life cycle analysis (LCA) is done on a proposed biomass production scenario before implementation. The LCA takes into account all carbon that is released and gained during the process of producing the biomass, from fertiliser application at planting, to the emissions caused by harvesting equipment. Life Cycle Analyses are typically done with intricate and data intensive models predicting the mitigation effects of specific biomass production scenarios could have, such as GORCAM (***Schlamadinger and Marland,*** 1999) and CO_2Fix (***Masera***, 2001; ***Mohren and Goldwijk,*** 1990). These models can also be modified for area specific studies, like CAMfor (***Richards and Evans***, 2000; ***Masera,*** 2001).

Biomass plantations are deemed an important potential source of biomass in many studies (***Cook and Beyea***, 2000; ***Matthews***, 2001; ***Berndes***, 2002; ***Cannell***, 2003; ***Niu and Duiker***, 2003). Apart from dedicated biomass plantations, the residues from forest plantations and associated industries are also considered to be a possible biomass source. Biomass plantations are also less likely to infringe on food security due to the product not having a dual purpose as a food source, like maize; and the possibility of the biomass plantations being planted on low productivity sites which will not interfere with the cultivation of food crops. The planting of trees on degraded land is also one of the mitigation strategies of the IPCC (Intergovernmental Panel on Climate Change) (***Nabuurs et al,*** 2007), furthermore the UNFCC (United Nations Forum on Climate Change) has attached a monetary value to the carbon that is stored in the soil, this may make the choice of trees as a bio-energy crop an even more attractive option to farmers wishing to diversify their crops. The carbon mitigation importance is increased with a coppicing rotation crop because the tree is harvested thus removing the carbon, but the stumps and roots can still potentially store carbon in the soil.

Literature suggests large variations of estimates for mitigation potential of forests (***Marland and Schlamadinger, 1997; Cook & Beyea***, 2000; ***Matthew***s, 2001; Berndes, 2002; ***Cannell***, 2003; ***Niu and Duiker***, 2003; ***Nabuurs et al,*** 2007). Potential oven- dry biomass yield over 25 years, can be in the vicinity of 10-25 t ha $^{-1}$ yr^{-1}, which translates to 5-12 t C ha $^{-1}$yr^{-1} of carbon storage (***Matthews***, 2001) in a seedling rotation plus 2 coppice rotations, which is not uncommon practice in the forestry industry. In Australia, average estimated potential atmospheric carbon sequestration from plantations ranges from 13 t ha^{-1} yr^{-1} for ***Pinus radiata*** to 15.8 t ha^{-1} yr^{-1} for Eucalyptus (***Fung et al.,*** 2002).

Planting biomass crops commercially increases the water usage, reducing available water. South Africa is already a water scarce country, and adding to the water usage demands will lead to a more severe water shortage even if rain fed crops are used (***Berndes***, 2002). Predictions suggest that the water scarcity problem will continue to increase with the effects of global warming and economic growth (***Berndes***, 2002). Thus, it is imperative to use all water resources that are available in the most efficient manner.

There are instances worldwide, where effluent and waste water have been used to irrigate woody crops (***Al-Jamal et al***, 2002; ***Berndes,*** 2002; ***Guo and Sims,*** 2003; ***Sudmeyer and Goodreid,*** 2007). The use of this effluent water to irrigate Eucalyptus trees may also open the scope to species that could viably be planted in the region. Scenarios where trees have been used in a phyto-remediation capacity, or grown in saline conditions have also proven to be successful (***Berndes***, 2002; ***Sudmeyer and Goodreid,*** 2007). The trees will use the saline or polluted, and otherwise unusable, water source and then produce a product that is environmentally friendly and can be used as a bio fuel.

1.3 Justification of study

The aim of this study is to assess the possibility of facilitating short rotation tree crops on sites with low agricultural production potential in the Winelands region of the Greater Boland Region. Currently, 107 662 ha of the Winelands region is used for woodlots and exotic plantations (***van Wyk et al.,*** 2001) and potentially an additional 106 000 ha is suited for woodlots (***von Doderer and Kleynhans,*** 2009).This publication is in no way advocating that the entire available area be planted for biomass, it is an estimate as to the amount of area that is potentially available for afforestation.

Bioenergy crops need to be planted on sites where tree taxa are well adapted to site conditions to be highly efficient and effective (***Schlamadinger & Marland, 1996***). This is the core purpose-to find a source of woody bio-mass that will efficiently use the space and site conditions that are available. Having these woodlots could be beneficial in this following ways: The woodlots could not only serve as a source of bio-fuel for energy on farms and surrounds, but also reduce the carbon footprint of farms. The reduction of carbon footprint could be beneficial when trying to export products to developed countries that are constantly scrutinized for their CO_2 use under the stipulations of the Kyoto protocol. The trees are to be planted in a woodlot manner and will be a dedicated biomass crop. In the selection of woody species suitable for biofuels, species were sought that: (a) are fast growing under prevailing climatic conditions; (b) not aggressively invasive in the landscape, biologically or aesthetically; (c) have good coppicing ability, for easy and rapid regeneration and increased carbon sequestration; and (d) have an acceptable density and calorific value . A genus of trees that fit this description well would be Eucalyptus and various taxa of this genus. Taxa are defined as taxonomic units which are phylogenetically related and have characters in common, which differentiate the group from other taxa. In this study the taxon unit could be referring to a species, provenance, hybrid or clone, thus the blanket term taxon is used (***Ride et al.***, 1999). Parallel studies investigating the difference in growth rate between fast growing indigenous species is underway, but quantifiable results will not be available for a number of years.

Historically, ***E. cladocalyx*** (Sugar gum) and to a lesser extent ***E. gomphocephala*** (Tuart tree) (***van Wyk et al.,***2001) has been planted extensively on farmland in the Greater Boland Region, partly for its beneficial effects on apiaries, but also as a generally well adapted all-purpose farmyard tree. Since that time, other species and hybrids have been developed in South Africa and abroad. Many of these taxa are untested in the Greater Boland Region.

1.4 Study objectives

The main objective was to assess the suitability of various tree crops that can be planted as woodlots for bioenergy in the study region. This was done by investigating the growth potential of several taxa in existing trials that are suited to grow in this region. The main focus of this study was: a) assess biomass production potential of specific families from provenances of historically planted taxa, namely; ***E. gomphocephala*** and ***E. cladocalyx***; and b) an investigation into other taxa that may be suitable but were not historically planted in this region as well as investigating possible threats to the these species.

Growth data from existing trials of fast growing Eucalyptus were analysed. These trials were situated on a wet and dry site to represent conditions prevailing across the study region. The differences in growth were analysed at different levels of specificity. An estimate of biomass production potential was made using selected density determinations and stand volumes. Furthermore, an investigation into alternative Eucalyptus taxa, aside from the traditional ***E. cladocalyx*** and ***E. gomphocephala,*** that could be planted in the study region was done. The specific objectives are as follows:

1. Investigate the differences in suitability of different taxa to be planted in different regions of the study area.

2. Estimate growth potential across climatic range in the study area and estimation of volume at 6 years of age.

3. Estimation of biomass available to harvest across a climatic gradient.

4. Taxa that are not historically planted in the study region are being assessed against the region's stalwart ***E. cladocalyx*** in a species trial. The taxa involved are as follows: ***E. grandis* × *urophylla, E. grandis* × *camaldulensis, E. grandis, E. dunnii and E. cladocalyx.***

The first part of this study is a species trial that is extended to yield more information on the biomass production potential of the taxa involved. There is not much literature on plantation forestry for the ***Eucalyptus spp.*** in the Greater Boland Region. This is because the climate differs greatly from the main commercial forestry regions in South Africa. Thus, a lot of literature from Australia and the Mediterranean region of Europe are cited. The second part of study compares growth of regional stalwart Eucalyptus taxa with commercially used taxa.

The key concepts around which the study revolves are: site species matching, the measuring and estimation of growth in species trials, biomass estimation and background knowledge on possible insects and pests that are common in commercial forestry.

A more detailed description of specific hypotheses set is discussed in the materials and methods section of this thesis.

Chapter 2: Literature review

Plantation or woodlots designed to supply biomass for purposes of bioenergy generation usually have the following characteristics:a) Fast-growing species are usually planted at high stand densities on short rotations with the aim of maximising biomass production, but with little emphasis on individual tree size (commonly small diameters) and have harvesting systems that are designed to utilize all aboveground biomass from the stand, but other variations exist (e.g. removal of woody biomass or removal of stem wood only). In specific cases, it may even include harvesting of the coarse root biomass. Bioenergy generation sometimes utilise solid pieces of wood/branches as feeder material, however, most commonly biomass is chipped and compacted to briquettes or pellets for greater efficiency of energy extraction (***Di Giacomo and Taglieri,*** 2009; ***Strehler,*** 2000; ***Serup et al.,*** 2002).

Currently there are few published studies investigating tree species that would be suitable for biomass production in this winter rainfall, drier region of the Greater Boland Region (***van Wyk et al.***, 2001; ***von Doderer & Kleynhans, 2009***). The general recommendation of ***Poynton*** (1979) was also used to find potentially suitable species. Early results of three experiments that have recently been planted to supplement the existing body of knowledge are located at Darling, Coetzenburg and Backsberg and are presented in chapter 4 of this thesis.

2.1 Measurement and estimation of stand growth from trial data

Bio-energy production from woody fuels will be governed mainly by the quantity of utilisable volume produced per hectare, the wood density and the calorific value of the biomass. Other factors such as piece size, uniformity, moisture content, tree height, survival, diameter at breast height (dbh) and stocking are important parameters and indicative of tree growth (***Darrow,*** 1994; ***Darrow,*** 1997; ***Dunlop et al.,*** 2002). Where trees are too young to have dbh and thus volume estimations, the heights of the trees is the only indicator of growth (***Darrow, 1997***).These parameters make it possible to assess and compare the growth characteristics on different sites.

Volume production is an indicator of growth potential. Tree height and dbh measurements are necessary to estimate the under-bark volume of a stand of trees. Equations to estimate biomass are often site and species specific. These equations are obtained from the correlations of many allometric relationships from extensive allometric studies. This however, was outside the scope of the present study. Stands grown for biomass production has some similarities with short-rotation pulpwood stands, e.g. comparable stand densities and harvesting systems. For this reason, volume equations developed for commercial pulpwood stands could be used in this study. A top-end diameter of 50 mm was used which does not differ much from some of the top-end diameters used in biomass equation studies, e.g. the top-end diameter of 40 mm was considered acceptable for biomass production in New Zealand (***Senelwa and Sims,*** 1998; ***Madgwick et al.,*** 1991***)***. The 50 mm upper diameter that was used in the volume equations is also appropriate for suggested existing harvesting technology (***von Doderer and Kleynhans,*** 2009), although most bioenergy crops advocate whole tree harvesting (***Madgwick et al.,*** 1991). Volumes of standing trees were thus estimated using standard equations that have been formulated based on extensive detailed measurement of the under-bark volumes of logs of many trees, with a top- end diameter of 50 mm. A commonly used equation in South Africa is the Schumacher and Hall equation (***Bredenkamp,*** 2000).

These equations, however, only estimate stem volume and not utilisable volume, because the equations make allowances only for the stump left in the ground, but not wastage or irregularities and imperfections with boles of trees. The equations only provide an estimate of total under-bark volume to a specified diameter (***Bredenkamp, 2000)***. In order to broaden the use of these equations, taper has been used to get an estimate of under-bark volume at any diameter. Taper is the relationship between height and diameter- as the height increases, the diameter decreases (***Bredenkamp, 2000***). Taper thus gives an indication of the stem profile and so allows for the estimation of volume at any height or diameter (***Bredenkamp, 2000***). The equations that have regression coefficients based on South African research uses the simpler taper equation, the Demaerschalk's function, to account for stem form with the result being more accurate volume estimations. Each taxon differs in growth rate and stem form, thus has a specific form factor as well as regression coefficient to estimate volume.

It is a very laborious task to collect enough information to calculate coefficients for species, thus the work has been done mainly on commercially important species and specific taxa in that species. Some of the taxa that form part of this study are not deemed as commercially important and thus no taxa specific, applicable form factors and regression co-efficient are available (e.g. ***E. gomphocephala***). In such cases alternative methods of volume determination need to be used, such as, the determination of volume without volume equations with use of an upper-stem diameter (***Finlayson,*** 2009***; Zöhrer, 1980***). The inclusion of a measurement of upper stem diameter can increase the accuracy of volume equations as it provides a good idea of the trees stem form. Pressler's method (1865) also known as the '***Richthöhenmethode***', uses upper diameter to increase accuracy by utilising reference height at which the diameter is half of that found at dbh (***Finlayson,*** 2009***; Zöhrer,*** 1980). Pressler deduced that this measurement results in a good estimation of stem form and thus the volume of the stem.

Practically, Pressler's diameter and height is measured with a Relascope. This measurement is expressed as a factor in relation to dbh (***Finlayson,*** 2009; ***Zöhrer***, 1980). The Bitterlich relascope can be read on different scales, namely 25m, 33m or 50m scale. The factors of each of the scales are different and so it seems to be best to use a constant scale throughout measurements in order to avoid confusion and incorrect calculations (***Finlayson,*** 2009; ***Zöhrer***, 1980).

With additional stocking data, it is possible to make estimate the wood mass production on a specific site on an area basis i.e. t ha^{-1} $year^{-1}$ (***Darrow, 1997***). The difference in mass estimation between sites will thus provide an indication to the difference in growth potentials on comparative sites.

2.2 Investigating alternative species for planting in the Greater Boland Region

The climate of the commercial forestry region in South Africa differs significantly from the climate in the Greater Boland Region. Thus commercially important species are not necessarily suitable for to the conditions in the study region. The study region has a Mediterranean climate with cool, wet winters and hot, dry summers. The annual rainfall ranges from 792 mm at Coetzenburg, the wettest site to 596 mm at Darling, the driest site. Backsberg has the highest mean annual temperature (MAT) of 23.5 °C while both Coetzenburg and Darling have a mean annual temperature of 18 ºC. The study region is also relatively free of snow and frost the main concern is the drought period of summer. The climate of the study region is discussed in detail in Chapter 3. This begs the question: which species, that are both fast growing and drought resistant, could be suited to the study region?

Species and provenance trials are not widespread and plentiful in the Greater Boland Region as a whole, much less so in the semi-arid region in which the study area falls. The suitability of growing eucalypts in a short-rotation, wood lot scenario has also not been as widely investigated as in the summer rainfall region of South Africa. There have, however, been studies in the Southern Cape, testing eucalypts for short rotation (14 year-18 year) saw timber (***Gardner et al.,*** 2003). Some of the taxa that were tested were ***E. globulus, E. nitens, E. saligna × urophylla, E. grandis × nitens, E. grandis × saligna*** (***Gardner et al.,*** 2003). The Southern Cape with its consistent rainfall distribution is, however, not climatically comparable to the Greater Boland Region. The key study in region for Eucalypts as a commercial crop in the Greater Boland Region is the work done at Pampoenvlei (***van Wyk et al.,*** 2001). In this study, known drought hardy taxa of the fast growing eucalypts were tested. A recent study investigating the feasibility of using woody biomass sources to generate electricity in the study region also named potentially suitable species of fast growing trees and made specific mention of Eucalyptus taxa (***von Doderer and Kleynhans,*** 2009). Many of the taxa that were potentially useful were evaluated by ***van Wyk et al.*** (2001) namely; ***E. grandis × camaldulensis, E. grandis, E. cladocalyx*** and ***E. gomphocephala*** (**Table 2.1**).

The difference in growth between unimproved seedlings and genetically improved material should be considered when assessing growth as both types of material will be present in the experiment. A trial was done in the Kwa-Zulu Natal Midlands and formed part of a study of the interaction of fertilisation, weed control and the effect of tree improvement on the growth of improved ***E. macarthurii*** and ***E. grandis*** seedlings (***van den Berg and Little, 2005)***. It was found that the improved seedlings had a significantly higher basal area than those of the unimproved seedlings and had better form and survival (***van den Berg and Little, 2005)***. New (unimproved) species and provenances should thus be evaluated with the potential for genetic improvement in mind.

The main criteria for the selection process were the climatic factors (Mean annual temperature (MAT), Mean annual precipitation (MAP), rainfall and altitude), hardiness towards drought and the usefulness of its timber for fuel wood (i.e. density and energy content).

Many ***Eucalyptus*** taxa are well known as fast growing, and commonly grown in commercial plantations, namely; ***E. grandis, E. nitens, E.smithii, E. dunnii, E. grandis × camaldulensis*** and ***E. grandis × urophylla***. Some eucalypts are more invasive than others, specific to this study, the species ***E. cladocalyx, E. grandis*** and ***E. gomphocephala*** were classified as a having a high potential to become invasive (Agricultural Research Council, 2009). This experiment in no way advocates that these taxa be planted on every piece of non- used land, because of their invasive capabilities. They should be planted and tended responsibly and be confined to demarcated areas away from water courses. The use of the commercial hybrid clones counter the problem of potential invasiveness because many of the hybrids are sterile. This could be a way of harnessing these useful, fast growing species in a manner that is also environmentally sound.

This study focuses on the growth of the drought hardy eucalypts and in no way claims that there are no other suitable, fast growing species that may be suitable in the study region. Interestingly, the growth of ***Acacia mearnsii*** and ***A. decurrens*** were found not to be competitive with the growth of the eucalypts in trials done in the Southern Cape (***Gardner et al.,*** 2003).There is however a parallel study being done, testing other tree species as well as indigenous tree species and comparing the growth to that of the eucalypts. Results from this study will only become available in a number of years.

Table 2.1 Climatic constraints of potentially suitable ***Eucalyptus*** taxa for the Greater Boland Region.

Species	**MAT range (°C)**	**Mean max. temp (°C)**	**Mean min. temp (°C)**	**Rainfall range in Southern Africa (mm.a^{-1})**	**Altitude (m.a.s.l.)**	**Drought hardiness***	**Traditional uses**
E. cladocalyx	18-20	30	8	400-700	0-600	Moderate	Poles
E. gomphocephala	17-20	29	7	300-1400	0-400	High	Fence posts
E. dunnii	15-19	29	8	800-950	900-1350	Very high	Pulp,saw timber
E. grandis	16.5-21.5	32	5	830-930	<1000	Moderate	Pulp, structural timber
E. grandis× camaldulensis	18.5-22	32	5	830-930	<1000	High	Pulp
E. grandis × urophylla	17.5-22	32	5	920-1000	<1000	High	Pulp

Sources: FAO, 1979; *Poynton*, 1979; *van Wyk, et al., 2001*; *Swain and Gardner*, 2003; *von Doderer & Kleynhans*, 2009.

*****Indicates class of ability to withstand drought, based on rainfall requirements

Most taxa in **Table 2.1** can potentially fit into the designated climatic silvicultural zone, Bw4, as prescribed by ***Poynton*** (1979); sub-humid (B), predominantly winter rainfall (w) and virtually frost free (4). Some of these taxa were also tested in the Pampoenvlei trial (***van Wyk et al., 2001***) and proved to have potential on the dry, sandy site. The Pampoenvlei trial, however, is a much drier than the Coetzenburg and Backsberg site and is more comparable to the Darling site as discussed in Chapter 3. Thus, some taxa might grow better on the sub-humid sites than the semi-arid sites and this still had to be tested.

2.3 Biomass and potential energy estimation:

Biomass in the scope of this study refers to the above ground matter namely; the stem, leaves, branches and bark of the tree, the parts of the tree that can be used for energy production with comparative ease. There are studies that include root systems as biomass (***Bouillet et al.,*** 2002; ***Gonçalves et al.,*** 2004; ***Stape et al.,*** 2004; ***Laclau et al.,*** 2008), but falls outside the scope of this study. In order to estimate the amount of energy that is available on a certain area, an estimation of the amount of biomass is critical (***Verwijst and Telenius***, 1999). This estimation can be done in a number of ways, broadly grouped into non-destructive and destructive methods, the more accurate being the destructive method (***Verwijst and Telenius,*** 1999).

Destructive methods are very time consuming and are not widely used in a commercial scenario, but the accuracy makes it widely used in the research environment. These methods include harvesting sample trees, physically measuring the biomass and its energy content and then using these values to extrapolate to a larger area. Sample trees of these destructive methods should be carefully chosen and be a true representation of the population which characteristics are being studied ***(Kumar & Pratt, 1996; Nùñez-Reguiera et al., 2001; Pèrez et al., 2006)***.

Allometry is the empirically- based description of the proportional change of one character in relation to another (***Medhurst et al., 1999***). This method is used to draw conclusions about biomass and other characteristics of the trees by using factors that are easily measurable such as dbh, height and taking samples of branches and leaves of trees. These methods have been used to extrapolate the estimated biomass across largely homogenous regions (***Hassal & Associates, 1998; Montagu et al., 2005; Pérez et al., 2006***) to give an idea of the carbon stock that is available.

Non- destructive methods of biomass estimation are a compromise between a required level of accuracy, the demand of the procedure as well as existing knowledge of the biological reality of the situation. Estimations using this method are obtained by measuring key indicators such as height, spacing and diameters of trees and then further more using appropriate volume equations and wood density data to produce biomass estimates (***Verwijst and Telenius,*** 1999).

Wood density is the ratio of mass of oven dry wood to its green volume and can be estimated in two main sample methods: by means of discs or increment cores (***Illic et al.,*** 2000). The discs can be taken if it is possible to do a destructive study on trees. Discs are usually taken at various intervals across the entire height of the tree and the density is then determined in the laboratory. Discs are taken at different intervals to assess and account for the difference in density across the length of the tree. Wood density does, however, increase from pith to bark of the tree. Density of annual rings also seems to be affected by rainfall due to a decrease in wood density with an increase in growth rate (***Illic et al.,*** 2000). In Eucalypts, however, literature has shown that unlike the softwoods, density remains fairly constant with an increase in height (***Illic et al.***, 2000). Using cores for wood density estimation is a non- destructive method of density estimation. The increment cores are taken at dbh and for increased accuracy, cores can be taken at different heights along the stem to get a better idea of transition in density.

The last step for bioenergy estimation would be a calorific value. The literature suggests that the calorific values of fast-growing eucalypts fall within a narrow range (***Munalula and Meincken***, 2009). An estimated calorific value of 18.4 KJ kg^{-1} (***Munalula and Meincken,*** 2009) was thus used to estimate the energy content of the top biomass producing families of the different species at the Darling and Coetzenburg sites. This calorific value was determined in an energy study for ***E. cladocalyx*** grown in the Boland Region and corroborates with other calorific studies (***Munalula and Meincken***, 2009; ***Pérez et al***., 2006; ***Pérez et al.,*** 2008; ***Reddy,*** 1994).

Biomass is in essence the volume of wood or plant material multiplied by its density (***Hassall and Associates***, 1998; ***Ravindranath and Ostwald,*** 2008). The contribution of leaves, fine and medium roots decrease in relation to increasing stem wood biomass, while the portion of biomass present in branches and coarse roots is larger in young trees (***Misra et al.,*** 1998). The general trend of increased biomass allocation to stem wood increases with tree size and age (***Madgwick et al.,*** 1991; ***Cromer et al.,*** 1993; ***Misra et al.,***1998). The biomass of roots are not being taken into account in this study and the biomass of the branches and leaves can be estimated to be approximately one third of the biomass of the stem as the focus is available above ground biomass in mature trees (***Hassal and Associates***, 1998; ***Montagu et al.,***2005; ***Pérez et al.,*** 2006). Similar work by ***Dovey*** (2009) suggests an average bark: stem wood ratio of 0.13 and a branches: stem wood ratio of 0.2 for 6 to 12 year old eucalypts in a South African context, which corroborates with work done on the branch and leaves: stem wood ratio's worldwide. The latter work was done on a wider age range of mature trees, with some stands being as old as 40 years. Thus it can be estimated that the portion of branches, leaves and bark amount to a fraction of between 0.25 and 0.30 of the stem wood. The stem wood: branch and bark ratio was done in the commercial forest region of South Africa with eucalypt stands being 6 years and older, thus the ratio of stem wood biomass to branches and bark at the experiment sites should be similar to this value, as they are planted in a similar fashion and are similar in age. When sampling the trees for biomass estimation, it is important to sample trees from all the dbh classes in the stand. The general consensus in the literature about wood density sampling is that all the dbh classes at the site should be sampled (***Montagu et al.,*** 2005; ***Illic et al.,*** 2000). Wood density within a taxon is dependant mainly on environmental factors like rainfall and differs more from the pith to bark than base to apex of the tree in ***Eucalyptus*** (***Illic et al.,*** 2000). Literature suggests that the average oven-dry density of fast growing ***Eucalyptus*** wood ranges between 430 and 660 kg m^{-3} (***Illic et al.,***2002; ***Clark,*** 2001; ***Pérez et al.,*** 2006; ***Dovey,*** 2009) with the general trend of higher densities on drier sites (***Montagu et al.,*** 2005).

2.4 Potential abiotic risks

The study region is free of frost, snow and wind risk. Fire is always a risk, but good management practices can minimise risks. The nature of some taxa present in this trial make it highly unlikely that they would have disease because most of the ***Eucalypts*** taxa that form part of this study have not been in present in South Africa long enough for disease causing agents to have grown accustomed to them (and they were imported with comparatively few diseases). In this regard, ***E. cladocalyx*** and ***E. grandis*** have a higher risk of disease as they are more commonly used commercial taxa. There are many pests that commercial forestry ***Eucalyptus*** species are susceptible to, but because of the Mediterranean climate of the study region, many of them are not of high risk (***Smith, Wingfield and Pertini***, 1996). There are, however, two pests that are potentially problematic in the region:

Gonipterus scutellatus

This pest (a snout beetle) is a leaf feeder and a major defoliator of host ***Eucalyptus*** (***Govender and Wingfield***, 2005)***.*** The pest is indigenous to Australia but occurs worldwide and was introduced into South Africa in the early 21st century. The larvae of the pest feed on the leaves of the trees, leaving tell-tale brown ‘tracks’, while the adults feed on older leaves and the green bark of twigs (***Atkinson,***1999). This pest can cause reduction in growth, coppicing, stunting of tree growth and possibly mortality. Females lay eggs in batches on the surfaces of young leaves. The eggs are covered by capsules formed by excrement (***FAO,*** 2007).

Thaumastocoris peregrinus

This pest has wide range of taxon of ***Eucalyptus spp.*** namely; ***E. viminalis, E. camaldulensis, E. grandis, E. terecticornis, E. smithii, E. grandis × camaldulensis*** and ***E. grandis × urophylla*** (***Jacobs & Neser,*** 2005; ***Noack &***

Coviella, 2006; ***FAO***, 2007; ***Agricultural Research Council,*** 2009). The pest is of Australian origin and the specific taxon that is found in South Africa originates in the region of Sydney. ***Thaumastocoris peregrinus*** is a sap sucking insect and is of commercial importance in South Africa (***Jacobs & Neser,*** 2005; ***Carpintero & Dellope,*** 2006). It reduces the photosynthetic ability of trees resulting in stunted growth or mortality in severely infested trees (***Jacobs & Neser,*** 2005; ***Noack & Coviella,*** 2006; ***FAO,*** 2007). The presence of ***Thaumastocoris peregrinus*** has been confirmed all over the country from Tzaneen to Cape Town.

Chapter 3: Materials and methods

3.1 Site descriptions

The Greater Boland Region is situated in the south of Western Cape Province, South Africa, the only province that has a Mediterranean climate. The region is a hub of agricultural activity, mainly with food crops, thus only marginal land is available for forestry projects. **Figure 3.1** indicates the main agricultural regions, the potential available land for forestry as well as the location of the experimental sites discussed in this study. This area is very widely used for agricultural purposes (**Table 3.1**) and so the degraded sites and grasslands are the only possible available land for woodlots, apart from the marginal tracts of land that form part of the cultivated land (**Table 3.2**).

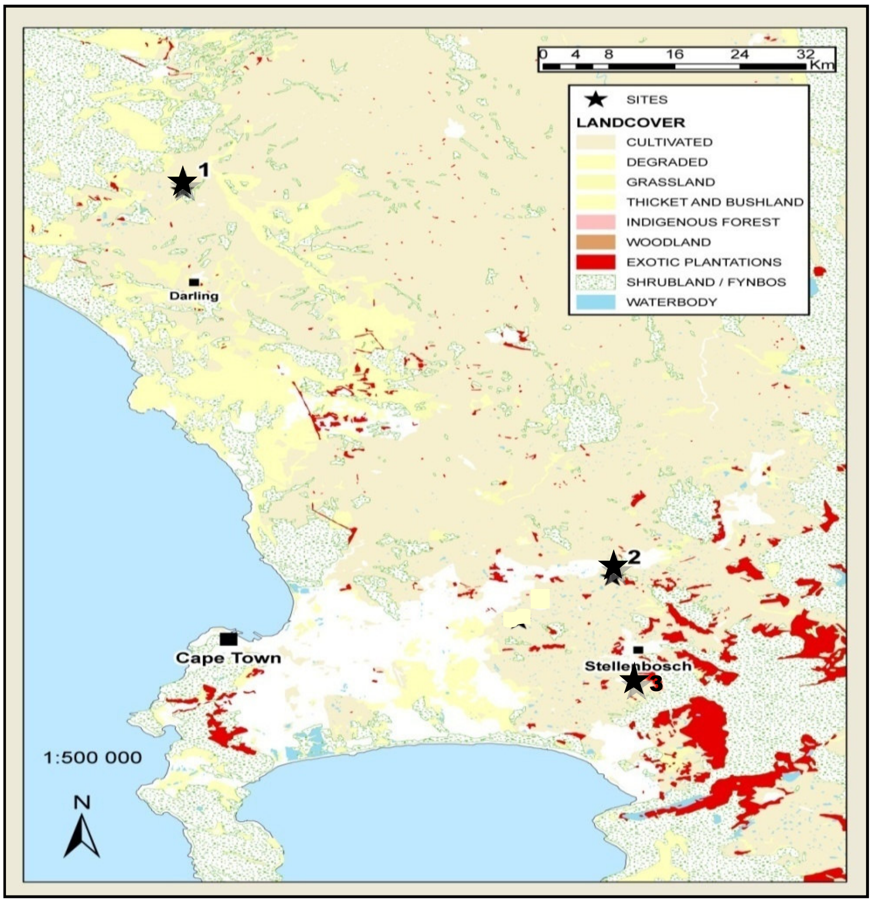

Figure 3.1 Map indicating main agricultural region, experimental sites and land type covers of the Greater Boland Region.

Table 3.1 Site names and climatic description of site numbers in Figure 3.1

Site Number	Site Name	Climatic description
1	Darling	Semi-arid
2	Backsberg	Sub-humid
3	Coetzenburg	Sub-humid

Table 3.2 Area allocated to various land uses in the Western Cape(Agricultural Research Council, 2008).

Land use	Area (ha)
Cultivated	2 256 270
Degraded	305 578
Grassland	120 878
Thicket and Bush land	653 527
Indigenous Forest	62 430
Woodland	2
Exotic Plantations	107 661
Scrubland/Fynbos	9 199 979
Water body	47 376

The three study sites (**Table 3.1**) can be categorised according to climate and water availability as follows: semi-arid, sub-humid (**Table 3.3)**. The climate on all three sites is strongly seasonal, with the duration of the dry summer being a key factor in determining tree stress. For this reason, the moisture growing season was calculated according to the FAO (1978) technique, i.e. the period where precipitation > 0.3 times potential evaporation. The mean annual values for potential evaporation from a class A pan (MAE_p) and precipitation (MAP) as well as the mean monthly values for rainfall (P) and the value ($0.3 * E_p$) of the three sites are depicted in the **Figure 3.2** (A to C). The period where $P > 0.3 * E_p$ is defined as the moisture growing season (FAO, 1978; ***Schulze et al.,*** 1997). There is a marked difference in water supply and atmospheric evaporative demand between the sites. Darling has the highest evaporation and lowest rainfall, while Backsberg has the highest rainfall and lowest evaporation. The moisture growing season appears to start slightly earlier at Coetzenburg than at Backsberg, but the duration is fairly similar. The moisture growing season at Darling is shorter than the other two sites and the moisture stress is greater in summer. Darling is the warmer site, having the highest minimum temperature, while the maximum temperatures are very similar across all sites.

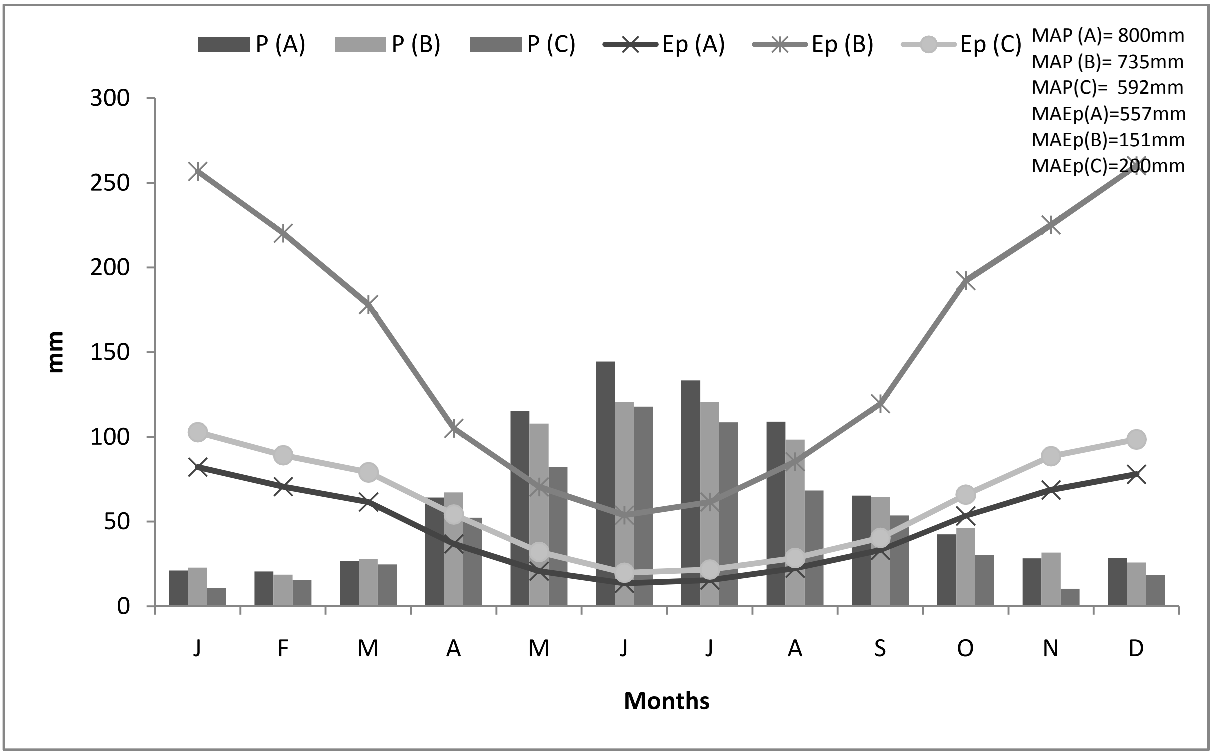

Figure 3.2 Average monthly precipitation (P) and Potential evaporation (Ep) at the three study sites: Backsberg (A), Coetzenburg (B) and Darling (C).

Table 3.3 Climatic information of the experimental sites

Climatic information	Backsberg	Coetzenburg	Darling
Mean Annual Rainfall (mm)	800	735	592
Mean Annual Temperature (°C)	17.5	17.3	18
Mean maximum of warmest month (°C)	28	28	29
Mean maximum of coldest month (°C)	6	8	8
Mean Annual Min Temperature (°C)	11	12	12
Altitude (m.a.s.l.)	220	250	70
Co- ordinates	33°50’09.28’’S 18º55’15.04’’E	33°57’07.69’’S 18°52’38.58’’E	33°16’08.20’’S 18°27’25.66’’E

3.1.1 Site descriptions and trial design sites

The Coetzenburg site is situated in Stellenbosch and is a sub-humid mountain site. The site is planted with provenances of ***E cladocalyx*** and ***E. gomphocephala***. The Darling site is located up the West coast of South Africa. It is the site that the represents the semi-arid region of the Western Cape Provnce. Backsberg is near Klapmuts just outside of Stellenbosch. The experimental design and climatic details of the sites are in **Tables 3.4** and **3.3.**

Table 3.4 Experimental design of the three trial sites

	Backsberg	Coetzenburg		Darling	
		E. cladocalyx	***E. gomphocephala***	***E. cladocalyx***	***E. gomphocephala***
Experimental Design	Latin square	Randomised Block	Randomised Block	Randomised Block	Randomised Block
Replications	5	5	5	6	6
Plots	25	268	96	290	108
Plot size	30 trees	4 trees/plot	4 trees/plot	5 trees/plot	5 trees/plot
Espacement	2m×3m (1667 sph)	2m×3.5m (1428 sph)	2m×3.5m (1428 sph)	2m×5m (1000 sph)	2m×5m (1000 sph)
Area (ha)	1.35	0.753	0.269	1.64	0.54
Date planted	5th July 2007	24-26 June 2003	26-27 June 2003	10-12 June 2003	13th June 2003

At the Backsberg site, square plots of 5×6 treelines were used, but only the inner 12 trees (4×3) were measured, thus leaving a surround of one line of trees around each plot. The plots at Coetzenberg and Darling are line plots consisting of 4 or 5 trees per plot without surround rows. The dbh and height of each tree was taken at each of the sites. Photos of these sites are shown in **Figures 3.3**, **3.4 and 3.5**. The specific information of families and provenances of the taxa at Coetzenburg and Darling are given in **Tables 3.5** and **3.6** and **Figure 3.5. Figures 3.6** and **3.7** shows that the ***E. cladocalyx*** provenances are from Southern Australia origin, while all but one provenance of ***E. gomphocephala*** is of West Australian origin.

Figure 3.3 Growth differences between taxa at the Backsberg site. The top picture displays the difference in growth between ***E. cladocalyx*** on the right in the foreground and the hybrids ***E. grandis × urophylla*** and ***E. grandis × camaldulensis*** on the right and left, respectively in the background. The leaf discolouration in bottom picture, illustrates the effects of a seasonal sulphur deficiency most probably caused by the waterlogging of soil in winter.

Figure 3.4 Differences in families' growth at the Darling site. The top picture illustrates the difference in potential growth on the site with ***E. gomphocephala*** on the left and ***E. cladocalyx*** on the right of the picture. The bottom picture illustrates the poor survival and growth of some of the ***E. cladocalyx*** at the site as well as the harsh site conditions these trees are growing on