

Effects of site management on growth, biomass partitioning and light use efficiency in a young stand of *Eucalyptus grandis* in South Africa

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Abstract

The effects of intensive site management treatments at establishment on the production ecology of a stand of *Eucalyptus grandis* were evaluated in South Africa. Treatments mimicked common operational practices in the region, and included slash removal, slash conservation, slash burning, topsoil disturbance through mechanised harvesting and fertilisation. We calculated the carbon distribution in the standing biomass from allometric relationships. Fine root turnover and litterfall measurements were determined using sequential coring techniques and litter traps, respectively, and this data was used to construct a full model of biomass allocation among stand components. Differences in nutrient availability to young trees, brought about by the most extreme site management treatments, produced several small but significant changes in the elements of the system's production ecology: Absorbed photosynthetically active radiation (APAR) increased from 210 to 247 Mmol photons ha⁻¹ over the 3-year monitoring period, apparent canopy quantum efficiency (α ; defined as gross primary production per unit of APAR) from 0.026 to 0.029 mol C (mol photon)⁻¹, and the fraction of carbon allocated to stem wood from 32.7% to 35.6% of net primary production. The magnitudes of these individual responses collectively described the increase in net primary productivity and the Type 1 timber volume response obtained. The biggest changes occurred in APAR, in contrast to published studies from higher rainfall environments where differences in nutrient availability caused greater changes in α than in APAR.

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1. Introduction

Eucalyptus grandis is the most important plantation hardwood in South Africa, occupying an area of 311 000 ha, 58% of the total of 541 000 ha planted to the genus *Eucalyptus* as a whole (FSA, 2003). Empirical research conducted during the last 30 years has shown large increases in productivity resulting from early, intensive silvicultural management operations that aim to optimise the supply of growth resources to the newly established crop (Schönau et al., 1981; Schönau, 1983, 1984, 1989; Herbert and Schönau, 1989, 1990; Little and van Staden, 2003). This silvicultural regime, i.e. appropriate slash management and site preparation techniques (Norris, 1995; Smith et al., 2000; Rolando et al., 2002), watering at planting where necessary (Viero et al., 2002), fertilisation at time of establishment (Herbert and Schönau, 1989, 1990; Herbert, 1996; du Toit and Carlson,

2000; du Toit and Oscroft, 2003), followed by intensive weed control up to canopy closure (Little et al., 1997; Little, 1999; Little and van Staden, 2003) has since become standard practice in southern African eucalypt plantations. Very few, if any, silvicultural tending operations are carried out from canopy closure until clear felling, since fertilisation and vegetation management practices after canopy closure have not yet been proven to be generally cost effective under water-limiting conditions commonly experienced in the study area (Little and Rolando, 2002). Despite the advances with early, intensive silviculture, a lack of a process-based understanding of tree growth in response to growth resource availability is currently constraining research efforts to increase productivity in a sustainable way. Increasingly, site-specific and operation-specific silvicultural regimes are needed to optimally manage the supply of growth resources (du Toit et al., 2000). An understanding of the response mechanism of the stand to changes in resource availability, brought about by silvicultural practices, will facilitate the extrapolation of results (Binkley et al., 2004; du Toit and Dovey, 2005).

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The growth rates of trees are governed by the quantity of absorbed photosynthetically active radiation (APAR) and the efficiency with which this radiation is utilised to convert atmospheric CO₂ to carbohydrates (Linder, 1985; Landsberg and Gower, 1997; Stape, 2002; Giardina et al., 2003; Binkley et al., 2004). The quantity of carbon assimilated (after respiration losses have been subtracted), is termed the net primary production (NPP) (Landsberg and Gower, 1997). Changes in the availability of growth resources can modify the quantity of absorbed PAR (through changes in leaf area), the canopy quantum efficiency (α) and the allocation of carbon to different plant parts (Linder and Rook, 1984; Landsberg and Waring, 1997; Landsberg and Gower, 1997; Albaugh et al., 1998; Bergh et al., 1999; Jokela and Martin, 2000; Stape, 2002; Giardina et al., 2003; Binkley et al., 2004; du Toit and Dovey, 2005). We consider the terms allocation and partitioning (in the context of describing the dynamic apportionment of NPP or assimilated carbon) as synonymous in this document, and we use the term distribution to describe the quantity of biomass contained in various parts of a standing crop of trees at a given point in time.

Several papers have been published on carbon distribution among biomass components of eucalypt stands worldwide (Bradstock, 1981; Tandon et al., 1988; Herbert, 1996; Misra et al., 1998; Hunter, 2001; Laclau et al., 2000; Xu et al., 2002), among many others. However, fewer studies have linked this with allocation to transient components, e.g. fine root production and litterfall, and even fewer have included estimates of above- and below ground plant respiration to calculate a stand-level carbon budget (Stape, 2002; Giardina et al., 2003). There is also limited information on the effects of changes in resource availability in eucalypt stands on respiration losses (Giardina et al., 2003). The partitioning of carbon, fixed during photosynthesis, is imperfectly understood (Landsberg and Gower, 1997; Gholz and Lima, 1997) and therefore, further research should focus on measuring whole-forest fluxes of carbon and water. An improved physiological understanding of carbon partitioning at the stand level could facilitate extrapolation of trial results and decision-making in forest management (Gholz and Lima, 1997; Binkley et al., 2004; du Toit and Dovey, 2005), especially through the use of process-based models (Waring, 2000; Mäkelä et al., 2001; Coops and Waring, 2001; Dye, 2001; Esprey, 2001; Landsberg et al., 2001; Sands and Landsberg, 2002; Almeida et al., 2003, 2004; Binkley et al., 2004).

Experimentation with growth resource manipulation (varying the supply of water, nutrients, light and CO₂ concentration) has been done on trees of varying age classes (and on eucalypts in particular). A number of papers have been published to demonstrate that seedlings (Cromer and Jarvis, 1990; Kirschbaum et al., 1992) and tree stands (Keith et al., 1997; Albaugh et al., 1998; Misra et al., 1998; Bergh et al., 1999; Hunter, 2001; Stape, 2002; Giardina et al., 2003) can vary their carbon allocation patterns as a result of changes in the availability of growth resources. Most of these experiments included treatments that resulted in very large and prolonged changes in resource availability, e.g. greenhouse trials with widely differing growth conditions, fertiliser field trials testing

large, repeated additions of nutrients, or water and nutrient optimisation experiments. While these experiments have demonstrated that changes in partitioning may occur, it is not certain whether similar changes will take place under less intensive site management treatments commonly used in industrial forestry. Data will be presented to illustrate the production ecology of *E. grandis* subjected to common silvicultural treatments, and to quantify the allocation of the NPP in the young stand. We will demonstrate how changes in growth resource availability affect APAR, α , and the partitioning of NPP to above-ground woody parts (η_w).

2. Materials and methods

2.1. Site, stand and experimental design

The Karkloof trial site is located at 29° 24' south and 30° 12' east at an altitude of 1260 m above sea level. The mean annual precipitation of 950 mm falls mainly in summer and the mean annual temperature is 15.2 °C. The soil is on average approximately 90 cm deep; it is clayey and rich in organic matter. More details on climatic conditions and the soil physical characteristics (du Toit et al., 2000) as well as basic soil chemical properties (du Toit, 2003), have been published. The site originally supported grassland vegetation, which was converted to an *E. grandis* plantation in 1964. The stand on the site was 7-year old at the time of harvest in December 1998. It had been the last of three coppice rotations and had a mean annual increment of 21 m³ ha⁻¹ year⁻¹. After clear felling the standing crop, site management treatments were implemented and a new crop of genetically improved *E. grandis* seedlings were planted. All treatments were subjected to complete chemical weed control up to the time of canopy closure. We studied growth responses across five treatments which were replicated in four separate locations on the trial site, yielding a total of 20 plots, each being 0.17 ha in size. The treatments (except for the 0S treatment) mimicked commonly used silvicultural practices:

- 0S Slash removed: All harvesting residue (including bark, branches and foliage) and litter layer manually removed from the plot.
- 1S Regular slash load: Harvesting residue retained and broadcast on the plot. This is regarded as the control treatment.
- SB slash burnt: Harvesting residue burnt in a medium intensity fire.
- SD topsoil disturbed: Slash disturbed and mixed with soil through mechanical loading and stacking of timber with a three-wheeled loader.
- SF fertilised: Regular slash, followed by a localised application of an N, P and Zn mixture near each seedling after planting.

2.2. Determination of stand volume and standing biomass

Tree growth measurements (tree survival, tree diameter and tree height) were conducted at three monthly intervals during

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