Quantifying Financial Returns from Commercial Forestry Research Trials in the Zululand Region of KwaZulu-Natal

by

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DECLARATION

By submitting this thesis electronically, I declare that the entirety of the work contained therein is my own, original work, that I am the sole author thereof (save to the extent explicitly otherwise stated), that reproduction and publication thereof by Stellenbosch University will not infringe any third party rights and that I have not previously in its entirety or in part submitted it for obtaining any qualification.

Daniel Dannyboy Seboa March 2018

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“Everything will be okay in the end. If it’s not okay, it’s not the end”

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DEDICATIONS

This thesis is dedicated to my late grandfather **Lucas Butana Seboa**.

I will forever strive to be humbled, disciplined, dedicated and resilient at all times to the best of my abilities.

ABSTRACT

South African plantation production is depended on a limited land resource. This limitation in land drives the goal of increasing production from the same land area. There is however a growing necessity for the justification of additional investments made towards intensive forest management practices. Thus, intensive forest management practices should maximize production yields at a reduced cost per hectare.

This study investigated site-specific financial returns of research field trials conducted at the ICFR. These trials included: (i) Site-Potential focusing on site specific fertiliser recommendations (FR), (ii) Forest management focusing on residue management (RM), vegetation and coppice management (VCM) and *Eucalyptus* regeneration (ER). According to the ICFR, these are the relevant research areas to address key challenges facing the South African forestry industry. The studied research trials where located in the Zululand region of KwaZulu-Natal. The region predominantly consists of *Eucalyptus grandis*, *Eucalyptus grandis* hybrids and other *Eucalyptus* species. The area is further considered to be highly productive for *Eucalyptus grandis* hybrids and clones.

Reported research findings were collected using a Meta-analyses Framework as an extractive tool. Thereafter, financial returns were determined using generic discounted cash-flow (DCF) models, which was followed by a sensitivity analyses to test results from the DCF models. Due to insufficient information presented from the Meta-analyses framework for ER research trials a cost comparison study was initiated on them.

The results from this study showed financial returns in FR research trials ranging from R49 201 and R273 524 ha^{-1} based on Land Expectation Values (LEVs) and 10 to 29% in Internal Rate of Returns (IRRs), the financial gains did differ per site. However, for mid-rotation FR research trials there were no financial gains. Financial returns for RM research trials declined through successive rotations, this could possibly be caused by soil compaction and the specific residue management techniques. Lastly, the financial returns for VCM research trials (vegetation management) and coppice management research trial returns were highly depended on cost-effective coppice reduction techniques.

Based on the results, the generic DCF model developed was successful in quantifying site-specific financial returns of three (FR, RM and VCM) of the four studied research fields.

OPSOMMING

Suid Afrikaanse plantasie produksie is afhanklik van beprekte grondbronne. Hierdie beperking in grond dryf die doelwit om produksie van dieselfde landarea the verhoog. Daar is egter ‘n groeiende vereiste om die ekstra beleggings in intensiewe bosbestuur praktye te regverdig. Dus moet intensiewe bosbestuur praktyke opbrengste verhoog teen ‘n verlaagde koste per hektaar.

Hierdie studie ondersoek groeiplek spesifieke finansiele opbrengste van navorsingsvelde wat deur die ICFR ondersoek is. Hierdie velde sluit in: (i) Groeiplek potensiaal met ‘n fokus op groeiplek spesifieke kunsmis aanbevelings (FR), (ii) Bosbestuur met ‘n fokus op bosafval bestuur (RM), (iii) Plantegroei en stomploot bestuur (VCM) en, (iv) *Eucalyptus* regenerasie (ER). Volgens die ICFR is hierdie die mees relevante navorsingsvelde om die sleutel uitdagings in die Suid Afrikaanse bosbou bedryf aan te spreek. Die navorsingsproewe wat bestudeer is geleë in die Zululand streek van KwaZulu-Natal. Die streek bestaan hoofsaaklik uit *Eucalyptus grandis, Eucalyptus grandis* hibriede en ande *Eucalyptus* spesies. Die area word beskou as hoogs produktief vir *E. grandis* hibriede en klone.

Gerapporteerde navoringsbevindings is versamel met die gebruik van ‘n Meta-analise Raamwerk as ‘n data-ontginnende metode. Hierna is finansiele opbrengste bepaal met die gebruik van generiese Verdiskonteerde Kontantvloei (VK) modelle, gevolg deur ‘n sensitiwiteitsontleding om die resultate van die VK te toets. Weens onvoldoende inligting vanaf die Meta-analise Raamwerk vir die ER proewe is ‘n kostevergelykende studie gedoen daarop.

Die resultate van die studie toon dat finansiele opbrengste in FR proewe wissel van R 49 201 tot R 273 524 ha^{-1}, gebasseer op Land Verwagtingswaarde (LEV) en tussen 10 en 29% vir Interne Renteverdienste (IRR). Die finansiele opbrengste het verskil per groeiplek. Die finansiele opbrengste vir RM proewe verminder gedurende opeenvolgende rotasies en kan moontlik wees weens grondkompaksie en die spesifieke bosafval bestuursmetodes. Laastens was die finansiele opbrengste vir VCM proewe (plantegroei bestuur) en stomploot bestuur proewe hoogs afhanklik van koste effektiewe stomploot verminderingstegnieke.

Volgens die resultate was die ontwikkelde generiese VK model suksesvol in die kwantifisering van groeiplek spesifieke finansiele opbrengste vir drie (FR, RM en VCM) van die vier navorsingsvelde.

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BCR	: Benefit-Cost Ratio
DAP	: Days after planting
DAFF	: Department of Agriculture, Forestry and Fisheries
DBH	: Diameter at breast height
DCF	: Discounted Cash Flow
EAI	: Equivalent Annual Income
ER	: *Eucalyptus* regeneration
FES	: Forestry Economic Services
FR	: Fertiliser recommendations
FSA	: Forestry South Africa
GAC	: General Annual Cost
GDP	: Gross Domestic Product
Gld	: Ground line diameter
IRR	: Internal Rate of Return
Ha	: Hectare
LEV	: Land Expectation Value
ICFR	: Institute for Commercial Forest Research
MAI	: Mean Annual Increment
NPV	: Net-Present Value
PPI	: Producer Price Index
PV	: Present Value
RM	: Residue management
Rot.Vol	: Rotation Volume at clear-felling
SD	: Survival difference
TI	: Treatment improvement
T.Cost	: Treatment cost
VCM	: Vegetation and coppice management
V_{mha}	: Total merchantable volume

1. CHAPTER ONE

GENERAL INTRODUCTION

1.1. BACKGROUND TO RESEARCH

Commercial forestry research in South African has been conducted for more than a century, and was firstly initiated by the then Department of Forestry (currently Department of Agriculture, Forestry and Fisheries) in 1912. The aim was to enhance information on silvicultural practices, timber properties, forest products and timber utilization (Olivier, 2009).

In recent years forest research has primarily focused on increasing wood production from limited land available for commercial forestry (Morris, 2008). This being important, considering that the forest industry contributes 0.6% to the Gross Domestic Product (GDP), and creates 60 200 direct jobs and a further 51 400 jobs in the processing sector during 2015 (Godsmark, 2017).

Investments made towards forestry research have been inconsistent. For instance, in 1989 it was recommended by Stratten (1989) that funding should be 1% of commercial sector turnover (Stratten, 1989 cited in Zwolinski, 1998). Yet, during the 1990's funding declined to 0.52% (Zwolinski, 1998).

Forestry South Africa (FSA) is the largest forestry timber grower's organisation in South Africa, with members controlling or owning 92% of all timber plantations (FSA, 2017). Grower's range from large (corporate growers, 11 companies), medium (commercial farmers, 1 100 individuals) and small (small-scale growers, 20 000 individuals) (FSA, 2017). FSA members are required to pay a R2.14 ton^{-1} levy per ton sold which generated around R32 538 000 from 15 205 000 tons sold in 2016, based on the FSA's members levy contributions (FSA, 2016a). From this amount a total of 70.7% (R27.8 million) was allocated to forestry research and forest protection in 2016 (FSA, 2016a). Considering that the total value of roundwood production was about R9.5 billion in 2015 (Godsmark, 2017), this amounts to 0.3% of the total value of roundwood production spent on FSA funded research in 2016.

Despite R42.7 billion invested towards commercial forestry in 2016 (Godsmark, 2017), the country is still facing a shortage of timber and is under pressure to meet national demand for sawlogs (DAFF, 2015). This situation is also mirrored in the rest of Africa where the supply of forest products (e.g. timber and fuelwood) is below predicted demand (Jacovelli, 2014). The situation highlights the importance of research conducted in commercial forestry, to increase wood production per hectare (Ha) while decreasing operational costs.

Burley *et al*. (1989) cited in Kowero and Splisbury (1997) found the capacity of research in Africa to be declining significantly. Already in 1997, Kowero and Splisbury (1997) further found that in the Southern African region, there is limited work conducted in assessing the capacity of forestry research and investigating how to improve the efficiency thereof. They further defined forest research capacity as "*the extent/degree to which a research institution is capable of effectively directing its resources towards the resolution of forestry and related problems*" (Kowero and Splisbury, 1997).

According to Kowero and Splisbury (1997), research institutions should provide a measure of its capacity in research outputs. Even though research outputs are commonly quantified with the number of publications produced, they do not provide the actual impact on the problems to which the research is directed. Furthermore, it's generally believed that academic research does not care much if their research results are applied or commercialized (Lunnan *et al*., 2004).

It appears there might be a necessity to pursue investigations on the value of research results (outputs) in commercial forestry. This has become evident in the development of industry projects analysing timber supply chains, were identified interactions and potential value adds of parts of these value chains are currently being investigated (Ackerman *et al*., 2014). As a result, the purpose of this study is to address these gaps that may hinder a more cost efficient and cost effective supply chain, in terms of the value and returns of commercial forestry research results.

1.2. RESEARCH PROBLEM

DAFF (2012), identified seven challenges facing forestry that included limited forestry research and development. In addition, Jacovelli (2014), puts forward the view that applied research is one of the key points for plantations in Africa to realize their potential.

The South African government further identified ten challenges facing sustainable development and management of forests, through the Forestry Roadmap in 2010 due to a decline in plantations and investments in the sector (Motaung, 2015). These challenges included a shortage of timber, monitoring and evaluations, research and development.

For the South African forest industry to remain globally competitive there must be a continuation in producing low-cost wood of the required quality for processors (Pallett and Sale, 2002). Producing high yields per unit area adds to the reduction of costs per unit of producing timber (Pallett and Sale, 2002). There have been several strategies used either in isolation or in combination to improve the productivity of re-established land (Sale, 2005). These include:

- Improved risk control, matching species to site to increase productivity.
- Improved silviculture, improving site preparation, planting practice, fertilisation and weed-control techniques.
- Tree breeding, resulting in continuous genetic improvement.
- Regime manipulation, through the use of different rotation lengths and planting densities on different sites (Sale, 2005).

Furthermore, increasing the productivity of plantations and reducing the cost of wood production is deemed necessary to meet the growing supply and consumption of wood and fibre. Species site matching is, for instance, an important tool in realising and sustaining maximum production potential (du Toit *et al*., 2010).

Anderson (1991. cited in Ghebremichael *et al*. 2005), argued that since there is no case for or against the economic viability of silvicultural investments, then net benefits of silvicultural investments can be regarded as insignificant. According to Ghebremichael *et al*. (2005), the economic consideration for applied intensive silviculture is critical as it determines if a company based on research results, will invest in enhanced silvicultural activities. Therefore, investing in intensive silviculture will mainly depend on the financial returns from such an investment. Considering that profitable plantation management depends on silvicultural practices that maximise production yields at the lowest possible cost (González-F *et al*., 2004).

A study done by Rietz *et al*. (2015), through stakeholder consultations on the future of research and how research should be reported, found that:

- Research results should be distributed to funders as early as possible.
- Research outputs should consider the economics of research findings.
- How research results affect economic, biological and social sustainability should be considered.
- The impact of research results must be quantified throughout the supply chain.

Literature has indicated that there are ways to successfully analyse and evaluate forestry research (Busby, 1992; McKenney *et al*. 1992; South *et al*. 2005; Harrison *et al*. 2010; Jones *et al*. 2010). A study by Morris (2008) found for instance that already in the 1980s research in forestry moved to mechanical soil preparation techniques, the use of fertilisers and chemical weed control. He highlighted how the output of forestry research and the application thereof have made significant contributions in increasing *eucalyptus* wood supply (Morris, 2008).

An investigation into value addition of forestry research as well as the development of methods to quantify the financial benefits of commercial forestry research in South Africa has merit in being investigated. Considering that, such evaluations can provide guidance for allocating research resources (McKenney *et al*., 1993). Equally important is how the research results are reported to the funders and the industry. The purpose of this study is to probe the value of research and the reporting of research results.

1.3. RESEARCH OBJECTIVES

The objective of the study are to:

- Systematically analyse literature on commercial forest research results and returns based on research trials, through the use of meta-analysis research methodology.
- Conduct financial analyses, based on commercial forest research results.
- Develop a sensitivity analysis, to determine the effect of the real discounted rate on the outputs of the financial analysis models.

Hyde (1985) defined technical change as the product of research, therefore, in this particular study technical change is referred to as research results. The questions that the study will seek to answer are:

- How can technical change be quantified financially, and what impact does the technical change have on a typical one-hectare pulpwood regime, when other parameters (input variables) are kept constant.
- What level of impact do cost differences have on different forest management practices based on research results (technical change).

The Institute for Commercial Forestry Research (ICFR) conducts research in five focus areas: (i) Forest Management, (ii) Risk Mitigation, (iii) Site potential, (iv) Hardwood Breeding (Wattle) and (v) Hardwood Breeding (*Eucalyptus*). According to the ICFR, these are the relevant applied research areas to address key challenges facing the South African forestry sector (ICFR, 2017). For the purpose of the research scope, the study focused on the following research trials at the ICFR:

I. <u>Site-Potential</u>; on-site specific fertiliser recommendations.
II. <u>Forest Management</u>; focusing on vegetation and coppice management; residue management; and *Eucalyptus* regeneration.

Research trials in Zululand, KwaZulu-Natal pertaining to *Eucalyptus grandis* and *E. grandis* hybrids and clones (e.g. *E. grandis x urophylla*) on a pulpwood rotation were investigated. Reason being, Zululand lying between 27°N and 29°S latitude is regarded as one of the most important plantation areas in South Africa (Little and du Toit, 2003; Fuller and Little, 2007; Gardner *et al*., 2007; Swain and Louw, 2009), contributing 20% of the country's hardwood pulpwood in 2005 (Gardner *et al*., 2007).

The region also predominantly consists of clonal forestry (*E. grandis*, its hybrids and with other *Eucalyptus* species), which are preferred species for production in the area (Swain and Louw, 2009). The Zululand region is highly productive for *Eucalyptus* growth (Rietz and Little, 2014), and further contributes more timber per unit area than any other area in South Africa (Fuller and Little, 2007).

1.4. RESEARCH METHODOLOGY

The study involved Meta-analyses of research trials at the ICFR, presented in the form of (i) Published articles; (ii) Bulletins; (iii) Technical notes; (iv) Thesis and unpublished “gray” literature. Further evaluation of these findings involved a cost-benefit analysis in determining the cause and effect of research results.

Discounted cash flow models were constructed based on trial data to simulate the inputs and outputs of research results. These models have been used in a scenario (sensitivity) analyses for each of the research disciplines. A number of constraints and limitations related to the methodologies adopted to the study were observed which included:

I. The availability of research trial papers and relevant information.
II. Detailed information on research trial results, rather than summaries.
III. A detailed understanding of what was researched.
IV. The quality of the research results (e.g. where only good results that yielded a response reported?)
V. Availability of costing information for trial inputs costs.

1.5. STUDY OUTCOMES

The outcomes of the study could provide: (i) better understanding of reporting on research results, (ii) a measure which can be used to assess current and past research programs, (iii) further justification for future research programs, (iv) an illustration of the point at which inputs from research results could lead to a decline in volume growth and an increase in input costs and, (v) an illustration of the challenges of financially evaluating plantations forestry research.

2. CHAPTER TWO
LITERATURE REVIEW

2.1. INTRODUCTION

This chapter will review literature on forestry research, with a greater focus on the evaluation of forestry research and benefits obtained from it. Furthermore, it will investigate research evaluation methods used by different countries or forestry research institutions, to justify current and future investments into forest research. The chapter will also draw on financial analyses methods used for forestry investment projects, and how these approaches are used to evaluate technical change as a product of research. Lastly, the chapter will look at benefits (returns) to evaluating research and the challenges facing research evaluation in South African commercial forestry.

2.2. FOREST RESEARCH IN SOUTH AFRICA

A discussion of forestry research will not be complete without a brief overview of the history of forestry research in South Africa. Three periods of forestry research can be identified in South Africa. These include the beginning of forestry research (from 1912 to the 1950s), a half a century of forest research (1950s to 2000s), and lastly the current research (2000s to current years) focus.

2.2.1. Beginning of forestry research

Commencement of forestry research dates back more than a century to initiatives by the Department of Forestry in 1912. Back then, the objective was to enhance information on silvicultural practices, timber properties, forest products and timber utilisation. Thus, the research conducted was to solve practical problems and provide a base for the South African forestry industry (Olivier, 2009). Moreover, Government and University conducted most of this research (Dyer and Wingfield, 2005).

2.2.2. Half a century of forestry research

During these years, the shift of research moved from solving practical problems to the establishment of forestry research institutions to service the rapidly expanding plantation forestry industry (Dyer and Wingfield, 2005). A number of these institutions were established, including the Wattle Research Institute (currently ICFR) in 1947 (Dyer and Wingfield, 2005; Olivier, 2009).

Forestry research then continued to focus on silviculture, yield studies, timber properties, timber seasoning, timber impregnation, forest products and forest hydrology (Olivier, 2009). Considering the increase in planting area during the 1980s and 1990s (Morris, 2008), there was an emphasis on cost efficient products, expansions and market share (Louw, 2006).

In 1985, the government withdrew their financial support from the ICFR, even though the value of timber sales between 1979 and 1986 had more than tripled from R697 million to R2 059 million and research funding declined in proportion to sales, leading to a downscaling in research activities (Louw, 2004).

2.2.3. Current research focus

The early 21st century saw the establishment of Forestry South Africa (FSA) the largest forestry organisation representing timber growers in South Africa (Olivier, 2009), which contributes approximately 70% of its budget to forest research (Louw, 2006).

In recent years, research had moved from focusing on solving practical problems in the 1900s to primarily focusing on increasing wood production from a limited land available for commercial forestry (Morris, 2008).

2.3. BENEFITS DERIVED FROM EVALUATION OF FORESTRY RESEARCH

Rolfe (1985) mentioned that research evaluation can provide the following benefits: (i) an increase in research productivity, (ii) better planning of research, (iii) aid in reaching research objectives and (iv) providing forestry research results in a much more cost-effective way. Further benefits of research evaluation include improving research performance and providing justification of new and past research programs (Skok, 1985).

Research evaluation also offers support for new funding and budget requests, further aids in decision amongst competing research projects. Furthermore, it allows the monitoring of currently ongoing research programs (Kowero and Splisbury, 1997). Quantification of research can aid in clarifying the assumptions necessary to economically justify particular types of research projects (McKenney *et al*., 1997).

2.4. BACKGROUND TO FOREST RESEARCH EVALUATION

The agricultural sector has a long history of studies in economic returns of research (Lunnan *et al*., 2004) but in forestry, such evaluation only gain interest from the 1960s onwards. The first application of forestry evaluation measures through ex ante analysis of cost and benefits was used in Southern pine genetic improvement research in the mid-1960s. The results were successfully used to clearly justify the budget of genetic tree improvement research (Fedkiw, 1985). Risbrudt (1985) considered work done by Robinson (1975) in technological change in forest industries as the beginning of research evaluation in forestry. Callaham (1981) and Seldon (1987), however, argued that research evaluation in forestry was firstly initiated by the United State Department of Agriculture (USDA) Forestry Services in 1979.

In comparison to agriculture, forestry during the mid-1980s was regarded as having little knowledge on linkages between forest productivity, supplies, prices and the productivity of research (Fedkiw, 1985). The problem is much more complicated than a lack of measurement of research productivity. At that time there were no measures of productivity of controllable forest management inputs (Fedkiw, 1985).

According to Hyde (1985), technical change can be regarded as a product of research, while Stier and Bengston (1992) defined technical change as the application of new knowledge to production processes. Hyde (1985) further explained that research is the input that produces new knowledge which results in an increase in yields and a decrease in costs.

According to Gregersen (1985) evaluation of research is needed for forest research planning and budgeting, and establishing approaches for estimating optimum forestry research budgets. This is especially relevant considering that the need to evaluate forestry research is increasingly driven by the ongoing decline in research budgets (McKenney *et al*. 1993).

2.5. APPROACHES TO EVALUATE FORESTRY RESEARCH RETURNS

A number of approaches for evaluating forestry research have been documented. These methodologies ranged from historical approaches mentioned by Cohen (1984), which do not yield any quantitative measures, to econometric studies used by Hyde (1985) and Seldon (1985), focusing on production functions, and index number technique used by Bengston (1985a). In addition, to consumer and producer methods, Hyde (1985), Seldon (1985), Bare and Loveless (1985) (estimating returns to forest nutrition) and Westgate (1985) (estimating returns to containerized seedlings) used supply functions to evaluate research returns.

Within the past years, modern approaches for evaluating the impact of forestry research focused more on cost analysis techniques using financial and (or) economic analyses methodologies. These approaches were used by McKenney *et al*. (1993) to evaluate the impact of Australian tree species selection in China. Financial analyses were also used to evaluate the impacts of intensive establishment of *Pinus taeda* (Jones *et al*., 2010) and to evaluate, financial retuns of forest reproduction materials in relation to nursery size (Harrison *et al*., 2010). In addtion to economic returns, land expectation value was used by Busby (1992), Dubois and Glover (2001), Ghebremichael *et al*. (2005) and by South *et al*. (2005).

2.5.1. Past Approaches for Evaluating Forestry Research Returns

The forestry research evaluation approaches listed below, make use of *ex-post* techniques to evaluate research projects and (or) programs:

I. Historical approach

This approach involves the use of a theoretical framework influenced by innovation, providing an explanation of induced innovation in historical time (Cohen, 1984). Stier and Bengston (1992) further described the approach to require a detailed enumeration of the sequence and timing of innovative activity for a particular field.

Cohen (1984) used a theoretical framework to map the pattern of technological change during 1915 and 1940 of the U.S. pulp and paper industry. However, he pointed out that an economic explanation of technological change was not sufficient to justify economic incentives. Furthermore, the approach failed to yield a quantitative measure of the rate of technical change or provide a standardized model (Stier and Bengston, 1992).

II. Econometric studies

The approach uses production functions focusing on the total output of past research investments, at the same time forsaking the interesting detail of specific events (Griliches, 1979). According to Bengston (1985b) the use of production functions to evaluate returns to research dates back to research studies by Tang (1963), Griliches (1964) and Latimer and Paarlberg (1965). The production function is regarded as the economist's term for the physical relationship between inputs and outputs (Hyde, 1985).

Stier and Bengston (1992) reviewed econometric studies focusing on timber harvesting and manufacturing industries. They reviewed a total of 24 studies dating back to a study done by Moreney (1968) on paper and allied products, and lumber and wood products. Furthermore, only two of these studies evaluated timber harvesting, first one by Stier (1982) on logging camps and contractors and later Martinello (1985) evaluated logging research.

There is a meaningful body of literature on econometric studies for evaluating the rate of technical change in the forestry sector. However, in terms of significant and consistent results, the body of literature is not exceptional (Stier and Bengston, 1992). Stier and Bengston (1992) further criticized any significant progress made, unless there were improvements in the development of conceptual and empirical measures.

III. Consumers and producers surplus methods

These methodologies are based on the standard supply and demand functions used by economists (Hyde, 1985). Economists use the function to study the economic impact of new research which tends to increase the productivity of factors of production (Seldon, 1985). Economic benefits determined from this approach are assumed to be calculated by the downward shift of the supply curve and (or) a reduction in production costs due to research (Seldon, 1987; Hellström *et al*., 1998). These methodologies further allow the estimation of the increase in consumer and producer surplus (Seldon, 1985).

Disadvantages of the consumers and producers surplus approaches include gains estimated from the functions being sensitive to the assumptions made regarding the supply and demand conditions (McKenney *et al*., 1993). Furthermore, Griliches (1979) argued that such studies are data and time expensive and particularly focus on successful innovations and fields. Seldon (1985) further highlighted a number of problems with supply functions which include determining the costs of research responsible for the innovation and the time frame of research costs (how far long in the past should research cost be accounted for). It is also difficult to determine how long the innovation will last, assuming that benefits due to research would last for a particular period (Seldon, 1985).

Seldon (1987) mentioned a number of studies using the consumers and producers surplus technique to estimate returns in forestry research from 1984 to 1987, which focused on:

- Structural particle board (Bengston, 1984)
- Aggregate lumber and wood (Bengston, 1985)
- Forest nutrition (Bare and Loveless, 1985)
- Lumber, plywood, pulp and paper (Haygreen *et al*., 1986)
- Containerized seedlings (Westgate, 1986)
- Softwood (Seldon, 1987).

The first study completed with the above-mentioned approach was the evaluation of innovations which led to the development structural particle boards (Seldon, 1987). Only two studies focused on forestry research being forest nutrition by Bare and Loveless (1985) and containerized seedlings by Westgate (1986) while, the rest of the studies focused on forest products.

IV. <u>Index number approach</u>

Research evaluation requires measuring the value of research outputs, but the value of the primary outputs of research cannot be measured directly (Bengston, 1985a). Hence, the index number approach makes use of growth in productivity to indirectly measure research output (Bengston, 1985a). The methodology in forestry studies has been used to estimate the rate of technical change (product of research) based on a value–added Cobb-Douglas production functions (econometric approach) (Stier and Bengston, 1992). The approach was derived by Bengston and Strees in 1984 termed the index of total factor productivity or technical change (Bengston, 1985a).

The following studies have used the index method approach by measuring the total factor of productivity (ratio of an index of outputs to an index of aggregate inputs) as mentioned by Stier and Bengston (1992):

- In the Canadian pulp and paper, and wood product industry Manning and Thornburn (1971) used the approach to determine the annual rates of technical change.
- Robinson (1975) evaluated the performance of the Lumber and wood product industries from 1949 to 1970.
- Risbrudt (1979) studied rates of technical change from 1958 to 1974 in the pulping and sawmilling industries.

The measured technical change for the above-mentioned studies were between 0.9% (pulp and paper industry) and 2.2% (sawmill industry).

The index number approach is regarded as being better than econometric approaches, as it is simpler to evaluate and does not suffer from limitations on degrees of freedom (Stier and Bengston, 1992). Bengston (1985a) further highlighted that the best part of the approach is its simplicity and directness. However, the approach does have drawbacks, as it does not provide any information on other production parameters of interest (Stier and Bengston, 1992). Overall the index number approach has low data requirements, as concluded by Bengston (1985a). Consequently, this is a plus as data is often a critical problem in developing evaluation methods for forest and forest products research (Bengston, 1985a).

Furthermore, researchers are seen to be moving more on a hybrid approach which combines the index number and the econometric approaches (Stier and Bengston, 1992).

2.5.1.1 Challenges with past approaches for evaluating research returns

Forestry in the past involved long rotations and production periods, a problem which was not found in agriculture (Jakes, 1988). Agricultural research evaluation methodologies depend highly on detailed data of output, inputs and prices, which were practically non-existent in forestry (Jakes, 1988). Fedkiw (1985) mentioned that, compared to agriculture, in forestry, there is little known about short (or long) linkages between forest productivity, supplies, prices and the productivity of forestry research.

The use of the value-added model (e.g. consumers and producers surplus approach) in wood product industries has no effect on the efficiency of intermediate inputs when determining technical change. However, in the forest industry when determining technical change the intermediate inputs are ignored as a source of productivity growth. These intermediate inputs include technological changes in forest management (intensive silvicultural practices, genetic improvements, etc.) or timber harvesting methods (Bengston and Strees, 1984).

These past evaluation approaches mentioned, tend to involve complex supply and demand models (e.g. Seldon, 1987), complicated econometric techniques using production functions (Stier, 1982) and index functions (developed by Bengston and Strees, 1984), which tend to ignore other production parameters.

2.5.2. Modern Approaches for Evaluating Forestry Research Returns

The following methodologies involve the use of cost analysis approaches by means of economic and financial analyses techniques. According to Cubbage *et al*. (2013) economic analyses (often referred to as benefit-cost analyses) compares projects costs and returns in social terms (net-social benefits). Although, economic evaluation studies carried out by Busby (1992), McKenney *et al*. (1992), McKenney *et al*. (1993), Dubois and Glover (2001), Ghebremichael *et al*. (2005) and South *et al*. (2005) compared only costs and returns.

Similarly, financial evaluation studies done by Ondro and Constantino (1990), Caulfield *et al*. (1999), Harrison *et al*. (2005), Cubbage *et al*. (2007), Jones *et al*. (2010) and Harrison *et al*. (2010) also compared costs and returns. These studies consider the costs and returns of carrying out a project in terms of market prices and not in relation to net-social benefit as done by economic studies (Cubbage *et al*., 2013).

McKenney *et al*. (1993) developed a cost analysis technique to determine the impact of forest research. The methodology provides an estimation of the reduced cost of production due to gains in volume (research productivity). The methodology further includes sensitivity analyses which provide a measure of the impact of different assumptions as the gains in research productivity are theoretical *(ex-ante*). Figure 2.1 provides a summary of the steps followed in evaluating the impact of research, including a sensitivity analyses for important parameter values (McKenney *et al*., 1993).

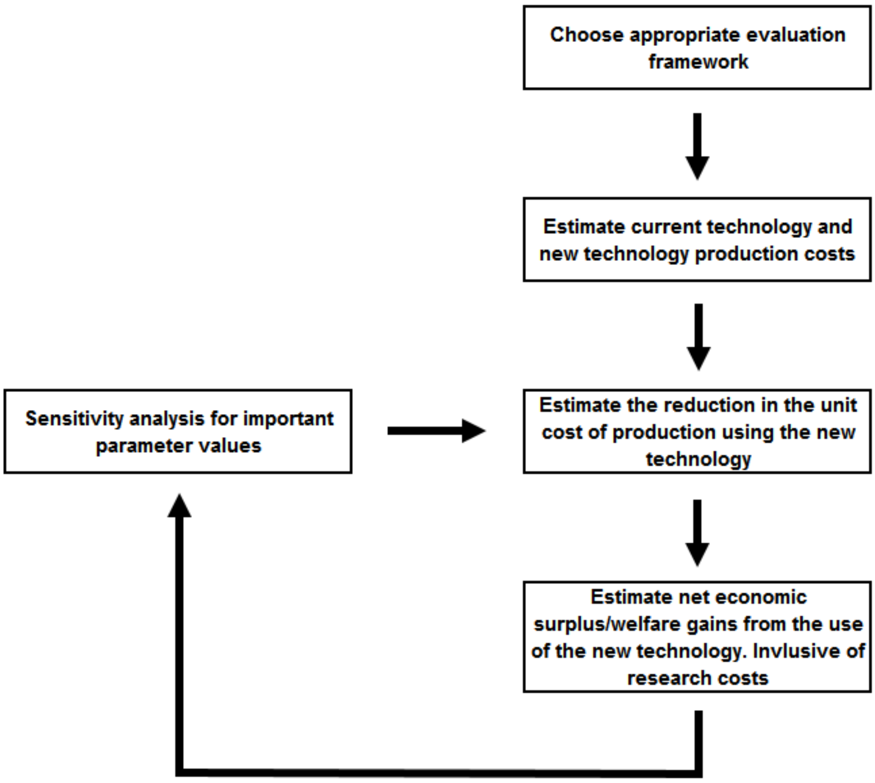


Figure 2.1: Steps in evaluating the impact of research using the cost analysis approach (Source: McKenney et al., 1993).

Cost analysis techniques entail correct identification of relevant costs for different silvicultural regimes (e.g. site preparation, planting, fertiliser, pruning and thinning). McKenney *et al*. (1993) highlight the need to consider that costs and outputs occur through time and thus the change in activities should be included in the analysis. The used of financial analyses (cost analysis) is generally intended to determine whether research (investment) projects will maximize profits of individual entities based on the cash flow of costs and returns (Cubbage *et al*., 2013). McKenney *et al*. (1993) used the cost analysis approach to determine the benefits of increased wood production by investigating the potential of fast-growing species trials.

The financial analyses techniques were used by Ondro and Constantino (1990) to estimate financial returns from fertilisation. Table 2.1 gives a summary of financial (or economic) studies carried out for estimating or evaluating the financial returns from research or intensive forest management practices. These studies indicate net-present value (NPV) and land (soil) expectation value as the most used preferred evaluation criterion estimators.

Table 2.1: Summary of financial (economic) analyses studies on the evaluation of returns (gains) to research results or the impact of alternative forest management practices.

Author(s)	**Country (Area)**	**Study Measure**	**Evaluation Criterion (Estimator)**
Ondro and Constantino (1990)	Canada (British Columbia)	Financial returns from fertilisation	NPV[a] and IRR[b]
Busby (1992)	USA	Economic evaluation of herbaceous weed control in *Pinus taeda* plantations	LEV[c]
McKenney *et al*. (1992)	Canada (Ontario)	Economic comparison of black spruce and jack pine tree improvement	NPV
McKenney *et al*. (1992)	China	Economic impact of tree species selection based on research results	NPV and IRR
Busby *et al*. (1998)	USA	Economics of site preparation and release treatments using herbicides	LEV
Caulfield *et* al. (1999)	USA	Financial returns from mid-rotation release in coastal plain *Pinus taeda* plantations	ROR[d]
Dubois and Glover (2001)	USA	Economic returns from alternative site preparation treatments	LEV
González-F *et al*. (2004)	Venezuela	Financial evaluation of a refertilisation trial	Net Benefit
Ghebremichael *et al*. (2005)	Canada (Alberta)	Economic analyses of growth effects of thinning and fertilisation of lodge pole pine	NPV, IRR, LEV and BCR[e]

Author(s)	Country (Area)	Study Measure	Evaluation Criterion (Estimator)
South *et al*. (2005)	USA	Economic gains from intensive plantation management	NPV
Harrison *et al*. (2005)	Philippines	Financial performance of exotic and indigenous tree species in smallholder plantations	NPV, IRR and LEV
Hawkins *et al*. (2006)	Canada (British Columbia)	Economics of site preparation	LEV
Cubbage *et al*. (2007)	South America and Southern United States	Timber investment returns from selected plantations	NPV, IRR, LEV, BCR and EAI[f]
Jones *et al*. (2010)	Southern United States	Financial analyses of intensive pine plantation establishment	NPV and LEV
Harrison *et al*. (2010)	Philippines	Financial returns of forest reproduction materials in relation to nursery size	NPV and IRR

a= Net-Present Value, b= Internal Rate of Return, c= Land Expectation Value, d= Rate of Return, e= Benefit Cost Ratio and f= Equivalent Annual Income.

These approaches varied from simple financial analyses used by González-F *et al*. (2004) to evaluate financial returns, were fertiliser costs were capitalised to rotation age and a net benefit was calculated, to studies carried out by Ghebremichael *et al*. (2005) and Cubbage *et al*. (2007), were financial performance measures were determined (NPV, IRR, LEV, BCR and EAI). Furthermore, financial analyse approaches to evaluating returns (gains) from intensive forest management, ranged from studies estimating returns from different fertilisation treatments (González-F *et al*., 2004; Ghebremichael *et al*. 2005), to the evaluation of different site preparation techniques (Busby *et al*., 1998; Dubois and Glover, 2001; Hawkins *et al*., 2006).

2.5.2.1. Challenges with modern approaches for evaluating research returns

The cost analysis approaches presented useful information on financial returns but, present uncertainties in long term research projects (McKenney *et al*., 1993). The approach further assumes costs and prices to be constant and they exclude salvage values (Harrison *et al*., 2010). Furthermore, according to Harou *et al*. (2013) forest investment analyses carried out with cash flow is unrealistic given changes to prices and costs, and policies affecting inflation, exchange and discount rates.

Financial analyses for forest investment projects lack the ability to provide accurate prediction of costs and returns from the initial investment (Ghebremichael *et al*., 2005). In this regard, McKenney *et al*. (1993) suggest that, financial analysis should consider performing sensitivity analyses of the results by changing input values, while Harou *et al*. (2013) argues that forest investment analyses should consider more inputs and outputs.

Cost analyses makes use of *ex ante* approaches to evaluate research returns, therefore, the returns are predicted (McKenney *et al*., 1993). On the other hand, past approaches mentioned earlier (Hyde, 1985; Seldon, 1985; Bengston, 1985a; Westgate, 1986), make use of *ex post* techniques.

2.6. FINANCIAL ANALYSIS METHODS FOR FORESTRY INVESTMENT PROJECTS

There is a considerable amount of literature on forestry investment projects using financial analyses based on capital budgeting techniques and criteria. Cubbage *et al*. (2007) cited studies by Davis *et al*. (2001), Klemperer (1996), Gregory (1987), and Brealey and Meyers (1991) that, adopted capital budgeting approaches. Considering how widely forest projects differ in nature, scope and size, e.g. from a small fuelwood plantation to a largely integrated forestry holding (Gregersen and Contreras, 1979), forest investment projects are generally carried out for:

- Purchasing of existing standing timber (Smith, 2010).
- Afforestation of purchased land (Smith, 2010).

- Decision making in forest management (e.g. choice of species, different silvicultural treatments, rotation age, and harvesting and transport methods) (Ham and Jacobson, 2012; Harrison and Herbohn, 2016).
- Identification of forestry systems offering positive net cash flows (Harrison and Herbohn, 2016).
- Selection of species offering greatest financial returns (Harrison and Herbohn, 2016).

Financial analysis is being carried out through financial models which involve simulation of incremental project costs and revenues (Harrison and Herbohn, 2016). However, these techniques tend to be biased towards forest investment projects with high timber prices, short rotations and modest initial and annual costs to maximize the present value of future returns (Zinkhan and Cubbage, 2003).

Financially analysis of forest investment projects is generally studied by means of discounted cash flow (DCF) analysis (Ham and Jacobson, 2012). Although, a major problem with the use of a DCF approach is the lack of flexibility with the model (Smith, 2010). The reason for this is forest investment projects are measured based on assumptions that future cash flows are deterministic and can be accurately predicted (Smith, 2010). Furthermore, Smith (2010) concluded that the use of a DCF approach in making decisions on forest investment projects diminishes the chances of the investment realizing its full potential value.

Harrison and Herbohn (2016) reported how forestry financial analyses have been poorly performed, due to the limited understanding of the technique. They further mentioned the following major problems with forestry financial analysis: (i) the failure to justify the chosen discount rate; (ii) the inclusion of sunk cost; (iii) the poor reporting of evaluation criteria; (iv) failure to include labour costs; (v) the failure to differentiate between constant and current price analysis and (vi) the lack of defining the project and the disclosure of the underlying assumptions (Harrison and Herbohn, 2016).

2.6.1. Discount Rate Selection for A DCF Analysis

A discounted rate selected is crucial in a DCF analysis for both net-present value (NPV) and land expectation value (LEV) (Ham and Jacobson, 2012; Zinkhan and Cubbage, 2003; Cubbage *et al*., 2013). This is due to cost and revenues found in a

DCF analysis, are discounted to a present value in year zero, and at times compounded to the rotation age as a future value (Ham and Jacobson, 2012).

The discounted rate can either be expressed in nominal terms or in real terms. Cubbage *et al*. (2013) recommended using a real discount rate in investment projects. The recommended discount rate can be determined by using the Fisher equation, which requires the nominal interest rate and inflation rate (Dayananda *et al*., 2002).

The decision criteria's discussed below are traditionally used as performance measures for evaluating the feasibility of forest investment (or decision making) projects based on DCF analysis.

2.6.2. Financial Performance Measures

A description of the financial performance measures is given in Table 2.2, which illustrates the equations and variables used to calculate the corporate finance measures as mentioned by Ham and Jacobson (2012).

Table 2.2: Description of functions and variables used to determine the value of financial performance measures as mentioned by Ham and Jacobson (2012).

Equation	Name	Function	Variables
1	Net-Present Value	$NPV = \sum_{t=0}^{n} \frac{R_t}{(1+i)^t} - \sum_{t=0}^{n} \frac{C_t}{(1+i)^t}$	Rt = revenue in year t; C_t = cost in year t; i = real discount rate; n = rotation age (project duration)
2	Equivalent Annual Income	$EAI = NPV \left[\frac{i(1+i)^n}{(1+i)^n - 1} \right]$	i = real discount rate; n = rotation age (project duration)
3	Benefit-Cost Ratio	$BCR = \frac{\sum_{t=0}^{n} \frac{R_t}{(1+i)^t}}{\sum_{t=0}^{n} \frac{C_t}{(1+i)^t}}$	Rt = revenue in year t; C_t = cost in year t; i = real discount rate; n = rotation (project duration)
4	Land Expectation Value	$LEV = \frac{\sum_{t=0}^{n} P_t (1+i)^{n-t}}{(1+i)^n - 1} - \frac{E}{i}$	P_t = net cash flow in year of the rotation (excluding land cost and GAC); E = general annual cost (GAC);

Equation	Name	Function	Variables
			n = rotation age; i = real discount rate.

The net-present value (NPV) represented by Equation 1 (Table 2.2) determines the difference between the present values of revenues and costs over a period of time (Ham and Jacobson, 2012). This corporate financial measure is mainly used in deciding on whether or not to undertake an investment on a project (Tassey, 2003). When the determined NPV is positive (NPV > 0), the investment project is accepted (Tassey, 2003; Zinkhan and Cubbage, 2003). On the other hand, if the NPV is negative (NPV < 0), the investment project is not accepted (Tassey, 2003; Zinkhan and Cubbage, 2003).

Determining NPV required the selection of an interest rate (real rate) to make an adjustment to the cash flows (Tassey, 2003). The discounted rate plays a critical role in the analyses of the investment project as discussed before. Furthermore, the NPV is regarded as giving the most accurate economic value, as it gives an absolute value for the economic benefits produced (Tassey, 2003).

The equivalent annual income (EAI) illustrated by Equation 2, is determined by converting the NPV to an annual value received the end of each year during the period of the investment project (Ham and Jacobson, 2012).

Cubbage *et al*. (2013) and Zinkhan and Cubbage (2003) defined IRR as “the discount rate that makes the present value of the benefits of a project exactly equal to the present value of the costs of a project”. Tassey (2003) indicated a general investment rule used when deciding on an investment project using IRR, that “*Accept the project if the IRR is greater than the discount rate. Reject the project if the IRR is less than the discounted rate*”.

The benefit-cost ratio (BCR) determined using Equation 3, can be easily expressed as the present value of revenues over the present value of the costs of a project (Ham and Jacobson, 2012). Once the BCR has been determined, values greater than 1.0 indicate that the investment project is acceptable. Conversely values lower than 1.0 indicate that the project is not accepted (Cozzarin, 2006; Cubbage *et al.*, 2013).

However, the BCR depends entirely on the accuracy of the discount rate (Tassey, 2003).

Land expectation value (LEV) also refers to as the soil expectation value (SEV) (or Faustmann formula) represented by Equation 4 is traditionally used for forestry valuations. The determined LEV provides an indication of the maximum amount an investor can pay for the land, while earning an acceptable rate of return (Smith, 2010). According to Hawkins *et al*. (2006), LEV is highly sensitive to the discounted rate, as the economic theory states that “increases in the discounted rate will reduce LEV and shorten the economic rotation length.

When comparing or deciding between two or more forest investment projects with unequal time periods, LEV is the suitable performance measures to be used in decision making (Dayananda *et al*., 2002; Cubbage *et al*., 2013). Considering that, NPV is limited in this regard as it cannot be used to compare projects with unequal time periods (Ham and Jacobson, 2012). Furthermore, decision makers prefer IRR over NPV as it measures benefits based on a rate of return they are familiar with (Dayananda *et al*., 2002). In addition, at certain instance IRR is preferred over NPV because the latter can simply be manipulated by investors by reducing the investment cost as far as possible (Smith, 2010).

2.6.3. Scenario Analysis with Forestry Investment Projects

Forest investment projects entail using financial models based on capital budgeting techniques and corporate finance measures. However, these use input costs, output prices, discount rates and production functions, which are susceptible to variability and measurement error. Therefore, sensitivity analyses should be performed to assess how the key components of the investment projects affect the financial returns (Cubbage *et al*., 2013).

Furthermore, a sensitivity analysis is carried out to verify and validate the financial model. Additionally, to determine the level of impact found in the errors of key parameters has on performance indicators (Harrison and Herbohn, 2016).

2.6.4. Meta-analysis of forestry research trials

For both financial and sensitivity analyses to be carried out, relevant information has to be collected for analyses. Meta-analysis technique can be used for gathering such information. This technique generally collects relevant studies which are based on addressing an issue and develops at least one indicator on the link investigated (Alston *et al*., 2000). According to Lipsey and Wilson (2001), a meta-analysis is appropriate for a body of research that consists of actual and quantitative results. Research which examined a similar relationship and their results can be configured in a comparable statistical form (Lipsey and Wilson, 2001).

The meta-analyses conducted in this study was applicable to the factors mentioned by Lipsey and Wilson (2001). However, it was considered that the trial research information cannot be configured in a comparable statistical form, as a financial analysis is performed in this regard. Furthermore, to successfully perform the analyses the research information needs to contain means, the standard deviation for experimental and control treatments (Piotto, 2008). Whereas information in this study did not consider the latter.

Forest investment methods using capital budgeting techniques are generally used for assessing and making decisions on forestry projects. The approach to this study, made use of similar techniques, as mentioned by McKenney *et al*. (1997) this approach involves investigations of how much production cost could change due to research needs being quantified. This is done for the purpose of determining net-gains encompassing research costs (McKenney *et al*., 1997).

Financial analyses approach of the study is similar to that used by McKenney *et al*. (1993) to provide a measure of the unit of cost reductions due to the research productivity (volume gains).

2.7. SUMMARY

This chapter reviewed literature on forestry research with an emphasis on research evaluation and benefits attained. Further reviewed past and modern approaches used for investigating (and/or quantifying) research evaluation. A substantial body of literature indicates that these research evaluation approaches have been widely used in North America.

For this particular study modern approaches used by McKenney *et al*. (1993), Ghebremichael *et al*. (2005), Harrison *et al*. (2005), Cubbage *et al*. (2007) and Jones *et al*. (2010) were adopted for investigating financial returns from forestry research.

3. CHAPTER THREE

METHODOLOGY

3.1. INTRODUCTION

The methodologies followed within this research study are a blend of qualitative meta-analyses and financial analyses in the form of simulated discounted cash-flow models. The meta-analyses techniques is a tool used to combine independent studies and measure the effective size of a treatment (Piotto, 2008). For the purpose of this study, meta-analyses are used to analyse results from research trials and to extract detailed research trial information on inputs and outputs for financial analysis. Furthermore, discounted cash flow models are used to provide financial results for evaluating research findings. The following methodologies will be discussed separately in this section of the study:

- A collection of empirical literature to identify research trials at the ICFR.
- A Meta-analyses study to gather information on research trials based on literature.
- A financial analysis by developing discounted cash flow (DCF) models, with the use of corporate financial measures.
- A scenario analyses predicted from discounted cash flow models.

3.2. COLLECTION OF LITERATURE TO IDENTIFY RESEARCH TRIALS AT THE ICFR

A literature search was carried out to identify research trials and to link them to collected information. This was done to perform a systematic analyses of the research through a meta-analyses technique and further perform financial analyses conducted with DCF models.

The data gathered in this section is important for financial analysis which follows. This information can limit the study when incomplete trial information is collected and the reported results required for financial analysis are poorly presented or not provided from the literature.

3.2.1. Literature selection

The literature on research trials collected from the ICFR included:

- Published papers
- ICFR Research Bulletin series
- ICFR Technical Notes
- ICFR Annual Research Reports
- Published Articles
- Unpublished thesis
- Other documents (additional papers from research staff unpublished).

Collected documents for trial identification at the ICFR had to meet the following criteria:

- ICFR research trials located in the Zululand area of KwaZulu-Natal.
- ICFR research trials in the following research fields, forest management (vegetation and coppice management; residue management; and *eucalyptus* regeneration), site potential (on site fertiliser recommendations).
- Trials focusing on *E. grandis* or *E. grandis* hybrid clones, including *E. grandis x E. urophylla*, *E. grandis x E. camldulensis* and *E. grandis x E. nites*.

A total of 40 research documents were collected and further categorised according to the following research fields: (i) on site-specific fertiliser recommendations (FR); (ii) residue management (RM), (iii) vegetation and coppice management (VCM) and (iv) *Eucalyptus* regeneration (ER).

Based on these research documents collected, Figure 3.1 indicates the number of documents collected per research field. A total of four documents gathered for FR, 10 for RM, 17 for VCM and nine for ER. A full description of these research documents is presented in Appendix A.

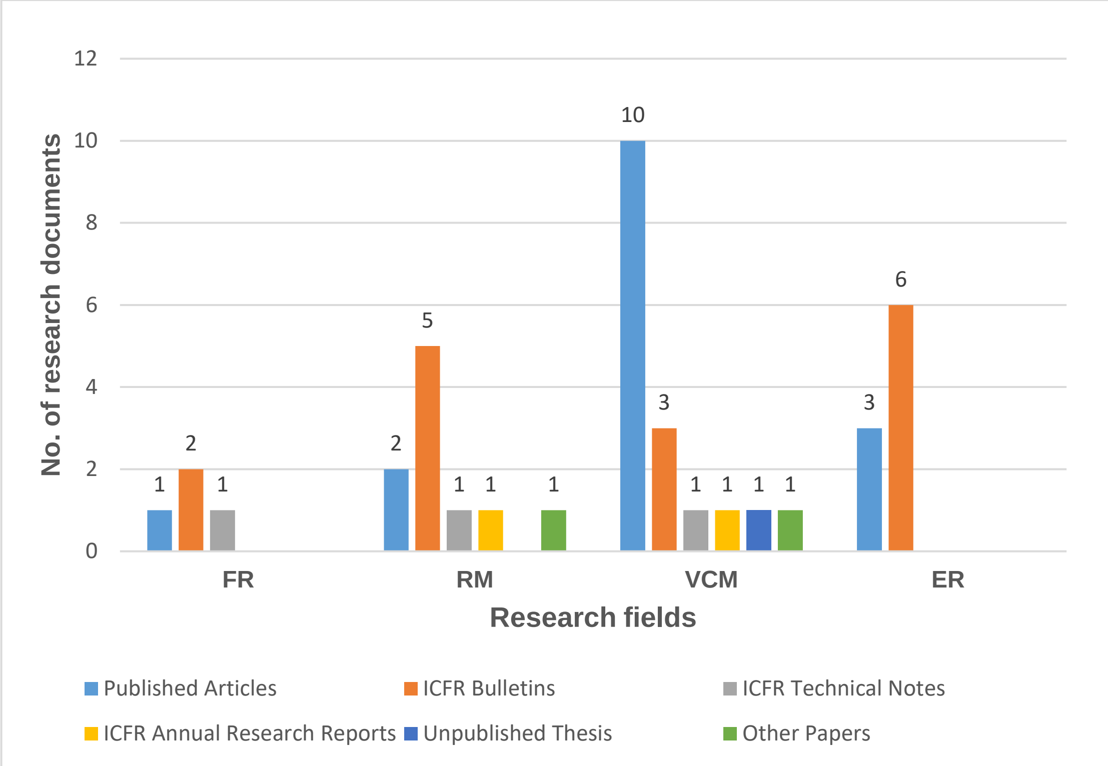


Figure 3.1: Number of research documents collected and further categorized according to four research fields.

Collected research documents focused on the application of fertiliser either at planting or at mid-rotation age for the FR research field. RM research papers investigated the effect of harvesting compaction and residue management on successive rotations. Then VCM research documents focused on different vegetation and coppice management techniques, and ER research documents investigated the effect of soil-amended hydrogel and water planting on tree survival rates.

3.3. A META-ANALYSES STUDY

For the purpose of this study, meta-analyses was used as a tool for extracting data on research results from trial information. A meta-analyses framework was constructed to examine the relationship between research trials and financial analyses. Descriptive statistics were used to compare research trials and to guide the financial analyses.

3.3.1. Meta-Analyses Framework

The following categories were used in developing the meta-framework:

I. Site and location details

Location of the trial (inland and coastal Zululand) as well as description of the study site, including climate (mean annual temperature and mean annual precipitation), and other site details such as soil type, altitude and previous land use.

II. Trial details

Duration of the trials (as most trials ran until rotation age) and last trial measurement age (for trials that did not run until rotation age).

III. Trial design and treatment details

Description of tested treatment, number of replication per treatment, planted tree species and number of trees per plot, trial and treatment area in hectares (ha).

IV. Yields

Determined yields of research trials obtained from the treatment plots. This was calculated at either rotation age or the last trial measurements as mentioned in literature. The following treatment means were documented:

- Diameter at breast height (DBH) in centimetres (cm).
- The basal area (BA) in meter squared per hectare (m^2 ha^{-1}).
- Tree height in meters (m).
- The volume at rotation or end of the trial in m^3 ha^{-1}.
- Tree survival (%) after specific days after planting (dap) before canopy closure.

V. Treatment rotation volume improvements compared to control

Total volume of the control treatment was compared to the tested treatment volumes. For this purpose Equation 5 below was used.

$$Treatment\ Improvement\ (TI) = \frac{(Treatment\ Value - Control\ Value)}{Control\ Value}\ X\ 100\% \qquad (5)$$

Where:

Treatment Value = Total volume per hectare (in m^3 ha^{-1}) of the treatment;

Control Value = Total volume per hectare (in m^3 ha^{-1}) of the control treatment.

From equation 5, the lowest (minimum), the average and the highest (maximum) treatment improvements (TI) were determined.

VI. Significant difference between treatments tested in the trial

Determine whether there were statistically significant or non-significant differences reported between different treatments tested. These are based on the total volume at rotation (end of trial) in m^3 ha^{-1}.

VII. Survival difference compared to control treatment

Equation 6 used by Viero and Button (2007) was used to calculate the survival difference (%) between the different treatments tested compared to the control treatment (dry planting).

$$Survival\ difference\ (\%) \frac{(Survival\ (water\ or\ hydrogel\ planting) - Survival\ (dry\ planting))}{Survival\ (dry\ planting)} X100\% \qquad (6)$$

Where:

Survival water = Tree survival rate percentage (%) of the water application treatment;

Survival hydrogel = Tree survival rate percentage (%) of the hydrogel application treatment;

Survival dry planting = Tree survival rate percentage (%) of the zero application of water and hydrogel treatment.

VIII. Significant difference between tree survival (%)

Determine whether tree survival (%) treatment means were reported as statistically significantly or non-significantly different.

3.3.2. Linking Meta-Analysis Framework with Financial Analyses Models

The information obtained from the meta-analyses was used to construct discounted cash flow (DCF) models for the different research trials. The meta-analyses data were used to define the following parameters for the DCF analysis:

- Treatments details, these determine the inputs of the model in terms of scheduling of activities.
- Trial durations determines the duration or length of the financial model.

- Yield (total volume per ha), determined two inputs parameters in the financial model, the total harvesting cost including transportation to pulp mill and pulpwood sales delivered to pulp mill.

3.4. DEVELOPMENT OF A FINANCIAL ANALYSES MODEL FOR THE ESTIMATION OF FINANCIAL RETURNS

Financial analysis is mostly used to provide insights into forestry investments and decision making of forestry projects (Harrison *et al*. 2005; Smith, 2010; Ham and Jacobson, 2012; Harrison and Herbohn, 2016). According to Harrison and Herbohn (2016), financial analyses can be used to evaluate different management options, such as decisions related to the implementation of research results, and timing of operational activities.

The following sub-section will explain the development of the financial analysis model using discounted cash flow (DCF) tables. It also describes the application of the DCF model in evaluating individual treatments per research trial and illustrates the cost comparison analyses for eucalypt regeneration (ER) research trials.

3.4.1. Financial Model Development

A generic DCF model for a 10-year pulpwood rotation in Zululand was developed. The model considered all income and costs per year for a one-hectare compartment (Ham and Jacobson, 2012) (see Figure 3.2 below).

The DCF cost data were obtained from the Forestry Economic Services (FES) cost benchmark report of 2014 (FES, 2014) (Unless specified otherwise). These costs from the FES were adjusted for time with Producer Price Index (PPI) inflation, as the DCF model was developed in 2016. Changes in the producer price index for 2015 and 2016 were 6.33 and 4.73% respectively (Liberta, 2016). Therefore, operational costs from FES were adjusted using the following equation 7:

$$Ajusted\ cost\ 2016 = Cost\ 2014\ x\ (1 + PPI\ 2015)\ x\ (1 + PPI\ 2016) \qquad (7)$$

Where:

PPI 2015 = Year on year producer price index change for 2015 at 6.33% (expressed as a decimal value);

PPI 2016 = Year on year producer price index change for 2016 at 4.73% (expressed as a decimal value);

Cost 2014 = Operational activity cost from FES (2014) (expressed in R ha^{-1}).

The following assumptions were made in developing the model, using a discounted cash flow analysis and financial performance indicators:

- The model assumed a Zululand plantation on a pulpwood rotation.
- The model identified operations scheduled for a pulpwood rotation.
- Cash flow table starts scheduling activities at year zero.
- Costs are in R ha^{-1}.

The development of the financial model was divided into the following:

I. Discounted cash flow model inputs
II. Discounted cash flow table
III. Financial performance criteria are generated from DCF table (outputs).

The complete generic DCF model is illustrated in Figure 3.2, comprising of the three building blocks listed above.

I. <u>Discounted cash flow model inputs</u>

Description of cost data for the generic DCF model is given by Appendix B.

II. <u>Discounted cash flow table</u>

The models DCF table was developed using real discount rates rather than using nominal discount rates (Ham and Jacobson, 2012).

Therefore, the real rate was calculated using the Fisher equation (8) below (Dayananda *et al.*, 2002):

$$r = \frac{(1+n)}{(1+p)} - 1 \qquad (8)$$

Where:

n = annual nominal interest rate (expressed as a decimal value);

r = annual real interest rate (expressed as a decimal value);

p = annual inflation rate (expressed as a decimal value).

The nominal and inflation rates used in the DCF model were 10.5% (Prime rate for 2016) (SARB, 2016) and 4.73% (Average PPI change for 2016) (Liberta, 2016) respectively, and the corresponding real rate used in the DCF was 5.5%. The present value (PV) was calculated in the cash flow table using the real rate. Equation 9 below was used (Ham and Jacobson, 2012):

$$PV = \frac{V_n}{(1+i)^n} \qquad (9)$$

Where:

V_n = future value in year n;

n = time period;

i = interest rate, or discount rate.

III. <u>DCF Model Outputs: Financial performance criteria's generated from DCF table</u>

Five performance criteria's were used for analyzing the generic DCF model, net-present value (NPV); equivalent annual income (EAI); land expectation value (LEV); internal rate of return (IRR) and the benefit-cost ratio (BCR).

1 - DCF Model Inputs

Activity	R ha-1
Land	13 568
GAC	2 324
Land preparation	2 511
Planting	2 771
Blanking	572
Fertiliser	506
Weeding	740
Harvesting	88 596
Sales	204 831

Rotation volume	
Rotation age	10 yr
Mean annual increment	16 t ha-1 yr-1
Rot.Vol	155 t ha-1

2 - DCF Table

Year	Activity	Direct cost (R ha-1)	General Annual Cost (R ha-1)	Total cost (R ha-1)	Gross revenue (R ha-1)	Net cash flow (R ha-1)	Present value (R ha-1)
0	Land value	13568		13568		-13568	
0	Establishment	6359		6359		-19927	-19927
1	Weeding	740	2325	3064		-3064	-2904
2	Weeding	740	2325	3064		-3064	-2753
3	Weeding	740	2325	3064		-3064	-2609
4			2325	2325		-2325	-1876
5			2325	2325		-2325	-1779
6			2325	2325		-2325	-1686
7			2325	2325		-2325	-1598
8			2325	2325		-2325	-1515
9			2325	2325		-2325	-1436
10	Clearfelling	50412	2325	52736	116550	77382	45302
10	Land value				13568		

3 - DCF Model Outputs

NPV	7218
EAI	419
LEV	30980
IRR	8%
BCR	1.4

Figure 3.2: Output from the generic DCF model, indicating the model inputs, cash-flow table and model outputs.

3.4.2. Generic DCF Model Application

The generic discounted cash-flow (DCF) model was used as a benchmark for three of the studied research fields, (i) on-site specific fertiliser recommendations (FR), (ii) forest management focusing on residue management (RM) and (iii) forest management focusing on vegetation and coppice management (VCM).

The generic DCF model was not used for the forest management focusing on *Eucalyptus* regeneration (ER). Reason being, the total volume at rotation was not reported in the ER research trials as data was only collected for 40 to 428 days after planting. However, a cost-comparison study was conducted, which is later presented in this section.

The data source for all trial costs are available in Appendix C where, total treatment cost were used as input values for the generic DCF model. The costing information includes the following:

- Labour cost.
- A number of units used on forest operation (e.g. application of fertiliser at planting needs 1.2 Man days per ha).
- The cost of treatment yields applied in R ha^{-1}.

Volume information from the meta-data in m^3 ha^{-1} was converted to tons per hectare (ton ha^{-1}) for the DCF analysis (m^3 ha^{-1} divided by 1.25). This conversion factor is based on pulpwood for other *Eucalyptus* species as mostly *E. grandis* hybrid clones were planted in the research trials (FSA, 2016b).

Treatment cost per additional tonne was calculated with the use of Equation 10, however, this was only determined for all the FR research trials and for VCM1, VCM3 and VCM4 research trials. Reason being, other research trials had similar treatment costs (e.g. VCM11), the same rotation volume (e.g. VCM6) and other research trials had no control treatment (e.g. RM4).

$$T.Cost\ per\ additional\ ton = \frac{Tested\ T.Cost - Control\ T.Cost}{Tested\ treatment\ Rot.Vol - Control\ Treatmen\ Rot.Vol} \quad (10)$$

Where:

T.Cost = Treatment cost (expressed in R ha^{-1})

Rot.Vol = Rotation volume (expressed in tons ha^{-1}).

Changes or modifications were made to the generic DCF model input variables (parameters) and length of planning period per research field. These are described below.

3.4.2.1. *On-Site Specific Fertiliser Recommendation (FR) Trials*

The main tested treatment for the research field was the application of fertiliser at different quantities (levels of fertiliser). Thus, the following changed were made to the generic DCF model for all 10 FR trials (changes are further illustrated in Figure 3.3):

- The cost (R ha^{-1}) of application of fertiliser per treatment in the trial.
- Rotation volume (in ton ha^{-1}) at the end of the trial.
- Rotation age adjusted to the length of the trial.

DCF Model Inputs	
Activities	R ha-1
Land	13 568
GAC	2 325
Land preparation	2 511
Planting	2 771
Blanking	572
Fertiliser	1 - FR trial treatment (x) cost
Weeding	740
Rotation volume	2 - FR trial treatment Rot.Vol (y) ton ha-1

DCF Table	
Length of planning period	3 - Trial duration (z) years

Figure 3.3: Modifications made to the generic DCF model for FR trials. The numbers refer to the changes made and (x) refers to the treatment number, (y) to volume and (z) refers to the trial duration.

3.4.2.2. *Forest management: Residue Management (RM) Trials*

The residue management trials had a range of treatments applied, the modifications to the generic DCF model were as follows:

<u>RM1</u>

The modifications made to the tested treatments as illustrated by Figures 3.4 are as follows:

- Change in planting costs.
- Rotation volume (in ton ha^{-1}) adjusted.
- Rotation age adjusted to the length of the trial.

DCF Model Inputs		
Activities	R ha-1	
Land	13 568	
GAC	2 325	
Land preparation	2 511	
Planting	1 - RM1 trial treatment (x) cost	
Blanking	572	
Fertiliser	2 - RM1 trial treatment (x) cost	
Weeding	740	
Rotation volume	3 - RM1 trial treatment Rot.Vol (y) ton ha-1	

DCF Table	
Length of planning period	4 - Trial duration (z) years

Figure 3.4: Modifications made to the generic DCF model for RM1 trial. The number refers to the changes made and (x) refers to the treatment number, (y) to volume and (z) refers to the trial duration.

RM2

The modifications made to the tested treatments as illustrated in Figure 3.5 are as follows:

- The inclusion of burning costs (burning residue before planting vs. no burning).
- Change in fertiliser costs.
- Rotation volume (in ton ha^{-1}) adjusted.
- Rotation age adjusted to the length of the trial.

DCF Model Inputs		
Activities	R ha-1	
Land	13 568	
GAC	2 325	
Land preparation	2 511	
Planting	1 - RM2 trial treatment (x) cost	
Blanking	572	
Fertiliser	2 - RM2 trial treatment (x) cost	
Weeding	740	
Rotation volume	3 - RM2 trial treatment Rot.Vol (y) ton ha-1	

DCF Table	
Length of planning period	4 - Trial duration (z) years

Figure 3.5: Modifications made to the generic DCF model for RM2 trial. The number refers to the changes made and (x) refers to the treatment number, (y) to volume and (z) refers to the trial duration.

RM3

The modifications made to the tested treatments as illustrated in Figure 3.6 are as follows:

- The inclusion of burning costs (burning residue before planting vs. no burning).
- The inclusion of pit preparation techniques (manual vs. mechanical vs. ripping). Land preparation costs from the FES 2014 Benchmark cost report includes the clearing of the bush, scrub, the remains of a previous crop, destumping, all methods of mechanical cultivation, ring weeding planting spots before planting, marking spots and pitting. In this regard, manual pitting techniques were assumed to be included in the total land preparation costs at R1 950 ha^{-1}. For instance, treatment 1 had a manual pitting technique applied, thus R0 ha^{-1} was added to the land preparation costs (assumed that it is already included). On the other hand, treatment 3 had a mechanical pitting technique applied (at a cost of R1 400 ha^{-1}), which is R550 ha^{-1} cheaper than manual pitting, and therefore R500 ha^{-1} was subtracted from total land preparation costs (further illustrated by Figure 3.6).
- Rotation volume (in ton ha^{-1}) adjusted.
- Rotation age adjusted to the length of the trial.

DCF Model Inputs

Activities	R ha-1
Land	13 568
GAC	2 325
Land preparation	2 511
Burning	2 - RM3 trial treatment (x) cost
Planting	2 771
Blanking	572
Fertiliser	3 - RM3 trial treatment (x) cost
Weeding	740
Rotation volume	4 - RM3 trial treatment Rot.Vol (y) t ha-1

1 - RM3 tiral treatment (x) cost

Pitting	R ha-1	Add to land Preparation
Manual	1 950	0
Mechanical	1 400	-550
Ripping	700	-1 250

DCF Table	
Length of planning period	5 - Trial duration (z) years

Figure 3.6: Modifications made to the generic DCF model for RM3 trial. The number refers to the changes made and (x) refers to the treatment number, (y) to volume and (z) refers to the trial duration.

RM4

The trial assumed all treatments had the same harvesting costs of R128 ton^{-1} ha at the roadside. Modifications made to the tested treatments (illustrated in Figure 3.7) are as follows:

- Change in fertiliser costs.
- Rotation volume (in ton ha^{-1}) adjusted.
- Rotation age adjusted to the length of the trial.

DCF Model Inputs	
Activities	**R ha-1**
Land	13 568
GAC	2 325
Land preparation	2 511
Planting	2 771
Blanking	572
Fertiliser	1 - RM4 trial treatment (x) cost
Weeding	740
Rotation volume	2 - RM4 trial treatment Rot.Vol (y) ton ha-1

DCF Table	
Length of planning period	3 - Trial duration (z) years

Figure 3.7: Modifications made to the generic DCF model for RM4 trial. The number refers to the changes made and (x) refers to the treatment number, (y) to volume and (z) refers to the trial duration.

3.4.2.3. Forest management: Vegetation and Coppice Management (VCM) Trials

The following trials had two type of main treatment factors, vegetation management (weeding to canopy closure) and coppice management (coppice control). Therefore, the modification made to the generic DCF model is described in the matric in Table 3.1. The table highlights the changes made to each of the VCM trials marked with (X), which also further indicated the main treatment factor (vegetation or coppice management). For VCM3 only four treatments (T1, T2, T4 and T5) were financially modelled out of the seven treatments because, the left out treatments had a similar treatment factor as modelled treatments. For VCM4 only four treatments (T1, T2, T3 and T8) were financially modelled out of the nine treatments. For VCM 5 research trial only treatment one to six were financially modelled out of 12 treatments and VCM 6 research trial only treatment two and four were not modelled.

Table 3.1: A description of the modifications made to the generic model for vegetation and coppice management (VCM) trials. These changes are marked by (X), alongside the VCM trial number and main treatment factor (vegetation or coppice management).

VCM Trial No.	Vegetation Management	Coppice Management	DCF Model Inputs									
			Activities (R ha-1)								Rotation volume	Planning period
			Land	GAC	Land preparation	Burning	Planting	Coppice reduction	Fertiliser	Weeding		
1	X								X	X	X	X
2	X									X		
3	X					X				X	X	X
4	X								X	X	X	X
5		X						X	X	X	X	X
6		X						X		X	X	X
7		X				X		X				
8	X								X	X		
9	X								X	X		
11		X						X			X	X

3.4.3. Cost Comparison Analyses

This analyses method was initiated for the forest management focusing on *eucalyptus* regeneration (ER) trials as these could not be financially analysed by making changes to the generic DCF Model. These trials investigated at tree survival rate and ground line diameter (gld) recorded between 80 and 428 days after planting (dap). This contrasts with FR, VCM and RM trials which reported volume as the primary output of tested treatments.

The cost comparison analyses investigated dry planting, water planting and hydrogel planting treatment factors, with tree survival rate as the primary output of tested treatments. This was done to compare the cost of planting and blanking at specific tree survival rates found on tested treatments. The following operational cost (R ha^{-1}) information was collected based on the ER trials treatments:

- Planting costs (includes labour and plants)
- Treatment cost (application of water and (or) hydrogel)
- Blanking cost (includes labour and plants).

Total costs included re-establishment (planting and treatment costs) and blanking costs. The re-establishment and blanking costs were determined as a percentage of the total costs based on Equation 11 below:

$$\%\ of\ Total\ Cost = \frac{Establishment\ or\ blanking\ cost}{Total\ cost} * 100\% \qquad (11)$$

The cost comparison analyses excluded ER2 and 3 trials for the following reasons:

- For ER2, tree survival rates were not reported for the tested treatments and all the plants in the control treatment (dry planting) died within the first week of planting.
- Only ground line diameter (gld) was reported in the ER3 trial.

3.5. A SENSITIVITY ANALYSES BASED ON DCF MODELS

A sensitivity analysis determines the level of influence inputs variables (or parameters) have on the financial performance indicators (Harrison and Herbohn, 2016). While a break-even analysis is used to determine range at which a cost variable can change when the project break-even at a net-present value (NPV) of zero (Dayananda *et al*., 2002). Although the break-even analyses can be regarded as a special application of a sensitivity analysis, its main aim is to analyse individual variable when NPV is zero (Dayananda *et al*., 2002). Sensitivity testing allows better decision making on variables identified as being sensitive (Dayananda *et al*., 2002). Furthermore, the identified variable should have the largest influence on the projects NPV (Dayananda *et al*., 2002).

The sensitivity analysed conducted in this study, however, identified the real discounted rate as an influential variable, and was further carried out to test the robustness of the land expectation value (LEV) at optimistic and pessimistic real discounted rates. From the determined financial performance indicators (LEV, NPV, EAI, IRR and BCR), the discounted rate is crucial in discounted cash-flow (DCF) analyses for LEV and NPV (Ham and Jacobson, 2012; Zinkhan and Cubbage, 2003; Cubbage *et al*., 2013). Furthermore, LEV instead of NPV is preferred when evaluating investment projects under identical conditions (Duku-Kaakyire and Nanang, 2004) and for comparing investment projects with different lengths (Dubois and Glover, 2001).

In this study, the sensitivity analyse was performed on the generic DCF model applications using the following procedure:

- The real discounted rate used for the DCF model applications was 5.5%, determined using the Fisher formula (Equation 8).
- Therefore, the real discounted rate was changed to optimistic values, 100 and 200 base points below the current real rate (5.5%) to 4.5 and 3.5% respectively.
- Additionally, changed to pessimistic values of 100 and 200 based points above the current real rate to 6.5 and 7.5% respectively.
- The LEV was identified as the sensitive variable, thus, this value changed based on the optimistic and pessimistic real discount rates used.
- Other parameters were kept constant in the DCF model during the sensitivity analyses.

The sensitivity analyses was conducted for three research fields discussed in the study, (i) on-site specific fertiliser recommendations (FR), (ii) forest management focusing on residue management (RM) and (iii) vegetation and coppice management (VCM) research trials.

4. CHAPTER FOUR

RESULTS

4.1. INTRODUCTION

From the 40 research documents collected, 33 research trials were identified for Meta-analyses. These trials were also identified from additional information from the ICFR research staff. Additionally, the ICFR re-establishment research project plans 2013 document (ICFR, 2013) was used to link research papers and trials. This includes vegetation management trials initiated in 1989, coppice management and *Eucalyptus* regeneration research trials initiated in 1992 and 2002 respectively. Furthermore, total numbers of trials per research field are as follows:

- On-site fertiliser recommendations (FR), ten trials.
- Forest management focusing on residue management (RM), four trials.
- Forest management focusing on vegetation and coppice management (VCM), eleven trials.
- Forest management focusing on *Eucalyptus* regenerations (ER), eight trials.

The primary output measure used in the research trials was volume, determined from either stem volume calculated from volume equations and (or) determined from merchantable volume (V_{mha} in m^3 ha^{-1}). According to Little and du Toit (2003) merchantable volume refers to “the under bark volume to a small end diameter of 7.5 cm). The meta-analyses framework results are fully described in Appendix D for all the trials analysed, including an indication of significant difference (or not) reported in the research trials.

The developed generic discounted cash-flow (DCF) model had a net-present value (NPV) of R7 218 ha^{-1}, equivalent annual income (EAI) of R419 ha^{-1}, land expectation value (LEV) of R30 980 ha^{-1}, internal rate of return (IRR) of 8% and benefit-cost ratio (BCR) at 1.4. The LEV was higher than the land value (R13 568) used in the DCF model and the determined IRR was also higher than the real discounted rate (5.5%). Therefore, the generic DCF represents a profitable ten-year pulpwood rotation working cycle and served as the benchmark against which the DCF models of the individual trials were compared.

This chapter will firstly present an overview of the meta-analyses framework results for all the research fields investigated in the study. Furthermore, it will provided individual research field trial results, these include: (i) meta-analyses framework, (ii) financial analyses, (iii) sensitivity analyse and (iv) a cost-comparison analyse results for ER research trials. Additionally, a summary (overview) of individual research field results is also presented in the chapter.

4.2. OVERVIEW OF META-ANALYSES FRAMEWORK RESULTS

4.2.1. Site Details

Climate conditions

Research trials occurred in Zululand regions (inland and coastal), where the average mean annual temperature (MAT) and mean annual precipitations (MAP) ranged between 19.6 °C and 1 002.5 mm respectively (Figure 4.1). Coastal Zululand was the wetter site with average MAP of 1 103 mm and an average MAT of 21.6 °C. While inland Zululand had an average of 902 mm and 17.6 °C, MAP and MAT respectively. According to the forest site classification based on climate used by Louw and Smith (2012), coastal Zululand falls under sub-tropical climatic zone (frost-free areas) and inland Zululand under warm temperate climatic zone (frost risk in low lying areas).

Soils

Trials located in the inland Zululand region had sandy clay loam soils with a high organic carbon content ranging from 3.9 to 6.4% and a high clay content. While coastal Zululand soils had a sandy to sandy loam texture with low organic carbon (<0.5%) and low clay content (<9%).

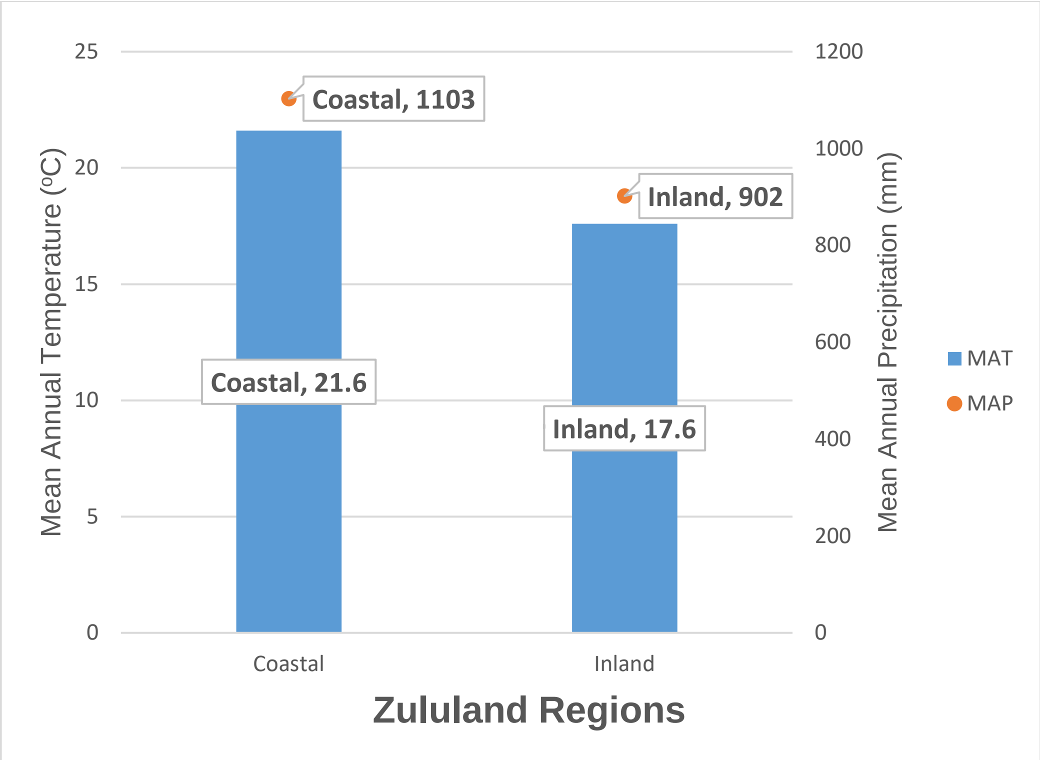


Figure 4.1: Average mean annual temperature (MAT) and mean annual precipitation (MAP) of two Zululand regions namely Inland and Coastal Zululand.

4.2.2. Experiment Trial Designs

According to Pretzsch (2009) in experimental trials, "planned treatments are carried out on the object under investigation to identify and quantify the cause-effect relationship". Furthermore, these experiments are compiled together to form a picture of entire systems, to support decision making in forestry. The disadvantage of experimental field trials is that factors such as climate, weather and CO_2 concentrations which influence growth cannot be controlled (Pretzsch, 2009).

A typical trial design for the 33 research trials included:

- Either randomised (or completely) block design, latin, factorial design and split or split-split plot design.
- The number of the treatments tested in the trial and the number of replications per treatment.
- A treatment plot consisted of 30 trees (other trials had up to 220 trees per plot), 5-row x 6 trees in each row. The inner plots of 12 trees (3 rows x 4 trees) in each row were measured. The average treatment plot area for the trials was 0.312 ha with a range of 0.0075 to 1.987 ha.

- The total trials size consisted of the total number of treatments plots in the trial. The trial consisted of 30 plots (6 treatments x 5 replications) and a total trial size of 0.675 ha (0.0225 ha per treatment plot).

4.3. ON-SITE SPECIFIC FERTILISER RECOMMENDATIONS

4.3.1. Meta-Analyses Framework Results for FR Research Trials

The main treatment factor was the application of fertiliser either at planting or after planting at different quantities. For the first four fertiliser recommendation (FR) trials (FR1, FR2, FR3 and FR4) fertiliser was applied at planting (in a ring around each tree and was slightly covered with soil after application). The next five research trials (FR5, FR6, FR7, FR8 and FR9) fertiliser was applied after planting at different years (mid-rotation fertiliser application) and for the FR10, fertiliser was applied one-year after planting.

Individual tree volume treatments were determined according to volume equations, for FR1 to FR4 and FR10, and then for FR5 to FR9 merchantable volume per treatment were determined at rotation age. The trial duration for FR1 to FR4 was 6.5 years but the last volume measurements were done at 6 years. Furthermore, there were significant difference in volume reported for tested treatment in FR1 to FR4 and FR10. However, for the mid-rotation trials (FR5 to FR9) there were no significant differences in volume reported for tested treatments.

Treatment improvements (TI) were calculated per research trial. The first four FR trials had maximum TI range of 15 and 20%, and an average of 7 to 12%. The lowest TI was treatment 3 from the first trial (FR1) at -3.8%. Likewise, mid-rotation fertiliser research trials had the low TI with FR6 and FR7 reporting TI's of -12 and -9% respectively. In addition, TI results for all the FR research trials are further illustrated in Figure 4.2.

Figure 4.2: The lowest, average and highest treatment improvements (%) relative to the control treatment for the FR research trials.

4.3.2. Financial Analyses Results for FR Research Trials

Financial analyses were carried out for all ten FR research trials, results are presented based on the different tested treatments per trial as follows:

4.3.2.1. DCF model results for FR1 research trial

The land expectation value (LEV) ranged from R187 201 to R233 261 ha^{-1}, and the treatments internal rate of return (IRR) differed slightly from 25 to 27%. Further results are indicated by Table 4.1. The LEVs of all the FR1 treatments were higher than the generic DCF model LEV and higher than the land value (R13 568) proving that the investment project was acceptable and more profitable than the generic DCF model.

The application of T6 cost R1 059 ha^{-1} more than the control treatment, but T6 increased volume by 15% and increased LEV by R35 319 ha^{-1}. Furthermore, the IRR increased from 25 to 27% indicating T6 as the most profitable treatment. However, T5 had the lowest treatment cost per additional tonne and could be regarded as the most cost effective treatment.

Table 4.1: The DCF model results for FR1 research trial treatments, including the total treatment cost and a description of the tested treatments.

Treatment	Treatment details	Treatment cost (Rands)	Rot.Vol (tons ha^{-1})	Treatment cost per additional tonne (R ton^{-1})	LEV (R ha^{-1})	NPV (R ha^{-1})	EAI (R ha^{-1})	IRR (%)	BCR
T1	0 [Control] Zero application of fertiliser	0	284		**197 942**	**57 628**	**3 344**	**25**	**1.74**
T2	0 g N + 21 g P + 0 g S Applied at planting	332	273	-32	**187 201**	**54 271**	**3 149**	**24**	**1.72**
T3	50 g N + 0 g P + 0 g S Applied at planting	566	284	707	**196 939**	**57 315**	**3 326**	**25**	**1.74**
T4	50 g N + 0 g P + 24 g S Applied at planting	744	303	38	**214 110**	**62 682**	**3 637**	**26**	**1.76**
T5	50 g N + 10.5 g P + 21 g S Applied at planting	799	321	21	**230 869**	**67 920**	**3 941**	**27**	**1.78**
T6	50 g N + 21 g P + 42 g S Applied at planting	1 059	325	26	**233 261**	**68 668**	**3 984**	**27**	**1.78**
T7	100 g N + 10.5 g P + 69 g S Applied at planting	1 581	319	45	**225 948**	**66 382**	**3 852**	**26**	**1.77**

Results marked in orange are below the LEV of the control treatment, while those in green are above the control treatment LEV.

4.3.2.2. DCF model results for FR2 research trial

The LEV ranged from R226 973 to R265 842 ha^{-1}, and the treatments IRR differed slightly between 27 to 29%. The application of T6 costed R1 210 ha^{-1} more than the control treatment, but T6 increased volume by 15% and increased LEV by R38 869 ha^{-1}. The IRR increased from 27 to 29% indicating T6 as the most profitable treatment. Although, T2 had the lowest treatment cost per additional tonne and could be regarded as the most cost effective treatment.

The LEVs of all the FR2 treatments were higher than the generic DCF model LEV and higher than the land value (R13 568) proving that the investment project was acceptable and more profitable than the generic DCF model. Results are further indicated by Table 4.2 below.

Table 4.2: The DCF model results for FR2 research trial treatments, including the total treatment cost and a description of the tested treatments.

Treatment	Treatment details	Treatment cost (Rands)	Rot.Vol (tons ha^{-1})	Treatment cost per additional tonne (R ton^{-1})	LEV (R ha^{-1})	NPV (R ha^{-1})	EAI (R ha^{-1})	IRR (%)	BCR
T1	0 [Control] Zero application of fertiliser	0	315		**226 973**	**66 703**	**3 870**	**27**	**1.78**
T2	0 g N + 21 g P + 0 g S Applied at planting	332	352	9	**260 587**	**77 209**	**4 480**	**29**	**1.82**
T3	50 g N + 0 g P + 0 g S Applied at planting	566	336	26	**245 325**	**72 439**	**4 203**	**28**	**1.80**
T4	50 g N + 0 g P + 24 g S Applied at planting	744	356	18	**263 302**	**78 058**	**4 529**	**29**	**1.82**
T5	50 g N + 21 g P + 42 g S Applied at planting	1 059	333	59	**240 519**	**70 937**	**4 116**	**27**	**1.79**
T6	100 g N + 10.5 g P + 21 g S Applied at planting	1 210	360	27	**265 842**	**78 852**	**4 575**	**29**	**1.82**
T7	100 g N + 10.5 g P + 69 g S Applied at planting	1 581	339	66	**244 496**	**72 180**	**4 188**	**27**	**1.79**

Results marked in green are above the LEV of the control treatment.

4.3.2.3. DCF model results for FR3 research trial

The LEV ranged from R197 942 to R227 583 ha^{-1}, and the treatments IRR differed slightly between 25 to 27%. Furthermore, the application of T6 costed R1 210 ha^{-1} more than the control treatment, but T6 increase volume by 15% and increased LEV by R35 643 ha^{-1}. Similarly, the IRR increased from 25 to 27% indicating T6 as the most profitable treatment. However, T2 had the lowest treatment cost per additional tonne and thus could be regarded as the most cost effective treatment.

All the tested treatments had LEVs higher than the generic DCF model and land value, thus, the investment projects was acceptable and much more profitable. Further results are indicated by Table 4.3 below.

Table 4.3: The DCF model results for FR3 research trial treatments, including the total treatment cost and a description of the tested treatments.

Treatment	Treatment details	Treatment cost (Rands)	Rot.Vol (tons ha^{-1})	Treatment cost per additional tonne (R ton^{-1})	LEV (R ha^{-1})	NPV (R ha^{-1})	EAI (R ha^{-1})	IRR (%)	BCR
T1	0 [Control] Zero application of fertiliser	0	284		**197 942**	**57 628**	**3 344**	**25**	**1.74**
T2	0 g N + 21 g P + 0 g S Applied at planting	332	316	10	**227 523**	**66 875**	**3 880**	**27**	**1.78**
T3	50 g N + 0 g P + 0 g S Applied at planting	566	317	17	**227 583**	**66 893**	**3 881**	**27**	**1.78**
T4	50 g N + 0 g P + 24 g S Applied at planting	744	314	25	**223 787**	**65 707**	**3 813**	**26**	**1.77**
T5	50 g N + 21g P + 42 g S Applied at planting	1 059	305	49	**214 713**	**62 871**	**3 648**	**26**	**1.76**
T6	100 g N + 10.5 g P + 21 g S Applied at planting	1 210	326	29	**233 585**	**68 769**	**3 990**	**27**	**1.78**
T7	100 g N + 10.5 g P + 69 g S Applied at planting	1 581	327	37	**233 206**	**68 651**	**3 983**	**26**	**1.78**

Results marked in green are above the LEV of the control treatment.

4.3.2.4. DCF model results for FR4 research trial

The LEV ranged from R220 522 to R251 776 ha^{-1}, and the treatments IRR differed from 26 to 29%. The application of T7 costed R1 582 ha^{-1} more than the control treatment, but T7 increased volume by 15% and increased LEV by R53 002 ha^{-1}. The IRR increased from 26 to 29% indicating T7 as the most profitable treatment. Although T7 had a higher treatment cost per additional tonne in comparison with T2 which had the lowest treatment cost per additional tonne. Thus, T2 could be regarded as the most cost effective tested treatment. Further results are indicated by Table 4.4 below.

All the treatments had a higher LEVs in comparison to the generic DCF model LEV and land value (R13 568). Thus, the investment project was acceptable and more profitable than the generic DCF model.

Table 4.4: Illustrates the DCF model results for FR4 research trial treatments, including the total treatment cost and a description of the tested treatments.

Treatment	Treatment details	Treatment cost (Rands)	Rot.Vol (tons ha^{-1})	Treatment cost per additional tonne (R ton^{-1})	LEV (R ha^{-1})	NPV (R ha^{-1})	EAI (R ha^{-1})	IRR (%)	BCR
T1	0 [Control] Zero application of fertiliser	0	308		**220 522**	**64 686**	**3 753**	**26**	**1.77**
T2	0 g N + 21 g P + 0 g S Applied at planting	332	340	10	**250 103**	**73 932**	**4 290**	**28**	**1.81**
T3	50 g N + 0 g P + 0 g S Applied at planting	566	343	16	**251 776**	**74 455**	**4 320**	**28**	**1.81**
T4	50 g N + 0 g P + 24 g S Applied at planting	744	333	30	**241 527**	**71 252**	**4 134**	**27**	**1.79**
T5	50 g N + 21 g P + 42 g S Applied at planting	1 060	338	35	**245 356**	**72 448**	**4 204**	**27**	**1.80**
T6	100 g N + 10.5 g P + 21 g S Applied at planting	1 211	338	40.2	**244 872**	**72 297**	**4 195**	**27**	**1.79**
T7	100 g N + 10.5 g P + 69 g S Applied at planting	1 582	370	26	**273 524**	**81 253**	**4 715**	**29**	**1.82**

Results marked in green are above the LEV of the control treatment.

4.3.2.5. DCF model results for FR5 research trial

The LEV ranged from R156 197 to R169 278 ha^{-1}, and the treatments IRR differed slightly between 22 to 23%. Tested treatments (T2 and T3) had a LEV of R13 081 and R10 884 ha^{-1} lower than the control treatment and were R3 139 and R5 706 more expensive respectively. The application of zero fertiliser at mid-rotation was much more profitable than the application of the two tested fertiliser yields. Furthermore, mid-rotation fertiliser reduced LEV and IRR by R10 884 ha^{-1} and 1% respectively, and the high treatment cost per additional tonne values indicate that the tested treatments were not cost effective.

All the tested treatments had a higher LEVs than the generic DCF model and land value. Thus, the investment project was acceptable and more profitable than the generic DCF model, further results are illustrated by Table 4.5 below.

Table 4.5: The DCF model results for FR5 research trial treatments, including the total treatment cost and a description of the tested treatments.

Treatment	Treatment details	Treatment cost (Rands)	Rot.Vol (tons ha^{-1})	Treatment cost per additional tonne (R ton^{-1})	LEV (R ha^{-1})	NPV (R ha^{-1})	EAI (R ha^{-1})	IRR (%)	BCR
T1	0 [Control] Zero application of fertiliser	0	253		**169 278**	**48 669**	**2 824**	**23**	**1.69**
T2	NPK [N + P + K] Applied 4.6 years after planting	3139	247	-550.7	**156 197**	**44 581**	**2 587**	**22**	**1.64**
T3	NPK+ [N + P + K + Ca + Mg + B + Cu + Zn] Applied 4.6 years after planting	5706	256	1729	**158 394**	**45 267**	**2 627**	**22**	**1.62**

Results marked in orange are below the LEV of the control treatment.

4.3.2.6. DCF model results for FR6 research trial

The LEV ranged from R11 729 to R26 272 ha^{-1}, and the treatments IRR differed slightly from 5 to 7%. Tested treatments (T2 and T3) had LEV of R14 543 and R12 162 ha^{-1} below the control treatment and were R3 139 and R5 706 more expensive respectively. The application of zero fertiliser at mid-rotation was much more profitable than the application of the two tested fertiliser yields. In addition, mid-rotation fertiliser reduced LEV and IRR by R12 162 ha^{-1} and 2% respectively.

The generic DCF model had a higher LEV than the FR6 treatments, proving to be more profitable. Treatment 2's investment project could not be accepted. The LEV was lower than the land value (R13 568) and the NPV was below 0. Further results are illustrated by Table 4.6 below.

Table 4.6: The DCF model results for FR6 research trial treatments, including the total treatment cost and a description of the tested treatments.

Treatment	Treatment details	Treatment cost (Rands)	Rot.Vol (tons ha^{-1})	Treatment cost per additional tonne (R ton^{-1})	LEV (R ha^{-1})	NPV (R ha^{-1})	EAI (R ha^{-1})	IRR (%)	BCR
T1	0 [Control] Zero application of fertiliser	0	162		**26 272**	**5 655**	**328**	**7**	**1.36**
T2	NPK [N + P + K] Applied 8.7 years after planting	3 139	143	-164	**11 729**	**-819**	**-48**	**5**	**1.25**
T3	NPK+ [N + P + K + Ca + Mg + B + Cu + Zn] Applied 8.7 years after planting	5 706	154	-713	**14 110**	**241**	**14**	**6**	**1.26**

Results marked in orange are below the LEV of the control treatment.

4.3.2.7. DCF model results for FR7 research trial

The LEV ranged from R108 706 to R143 052 ha^{-1}, and the treatments IRR differed by 17 to 21%. Furthermore, tested treatments (T2 and T3) had a LEV of R14 895 and R34 346 ha^{-1} below the control treatment and were R3 139 and R5 706 more expensive respectively. The application of zero fertiliser at mid-rotation was much more profitable than the application of the two tested fertiliser yields. In addition, mid-rotation fertiliser reduced LEV and IRR by R14 895 ha^{-1} and 2% respectively. Further results are illustrated by Table 4.7.

All the treatments had higher LEVs compared to the generic DCF model and land value. Thus, the investment project was acceptable and more profitable than the generic DCF model.

Table 4.7: The DCF model results for FR7 research trial treatments, including the total treatment cost and a description of the tested treatments.

Treatment	Treatment details	Treatment cost (Rands)	Rot.Vol (tons ha^{-1})	Treatment cost per additional tonne (R ton^{-1})	LEV (R ha^{-1})	NPV (R ha^{-1})	EAI (R ha^{-1})	IRR (%)	BCR
T1	0 [Control] Zero application of fertiliser	0	225		**143 052**	**40 472**	**2 348**	**21**	**1.64**
T2	NPK [N + P + K] Applied 3.6 years after planting	3 139	218	-436	**128 157**	**35 816**	**2 078**	**19**	**1.58**
T3	NPK+ [N + P + K + Ca + Mg + B + Cu + Zn] Applied 3.6 years after planting	5 706	204	-273	**108 706**	**29 737**	**1 725**	**17**	**1.52**

Results marked in orange are below the LEV of the control treatment.

4.3.2.8. DCF model results for FR8 research trial

Land expectation value ranged from R25 536 to R31 432 ha^{-1}, and the treatments IRR differed insignificantly (7 to 8%). The tested treatments (T2 and T3) had a LEV of R5 906 and R3 701 ha^{-1} below the control treatment and were R3 139 and R5 706 more expensive respectively. The application of zero fertiliser at mid-rotation was much more profitable than the application of the two tested fertiliser yields. Furthermore, mid-rotation fertiliser reduced LEV and IRR by R3 701 and 1% respectively and the tested treatments had high treatment cost per tonne values indicating that the rotation volume could not compensate for the treatment costs.

The generic DCF model had a higher LEV than treatment 2 and 3 and proved to be more profitable. Further results are indicated by Table 4.8.

Table 4.8: The DCF model results for FR8 research trial treatments, including the total treatment cost and a description of the tested treatments.

Treatment	Treatment details	Treatment cost (Rands)	Rot.Vol (tons ha^{-1})	Treatment cost per additional tonne (R ton^{-1})	LEV (R ha^{-1})	NPV (R ha^{-1})	EAI (R ha^{-1})	IRR (%)	BCR
T1	0 [Control] Zero application of fertiliser	0	121		**31 432**	**6 224**	**361**	**8**	**1.31**
T2	NPK [N + P + K] Applied at 5.7 years after planting	3 139	122	3924	**25 526**	**4 166**	**242**	**7**	**1.27**
T3	NPK+ [N + P + K + Ca + Mg + B + Cu + Zn] Applied 5.7 years after planting	5 706	131	554	**27 731**	**4 934**	**286**	**8**	**1.26**

Results marked in orange are below the LEV of the control treatment.

4.3.2.9. DCF model results for FR9 research trial

Land expectation value ranged from R7 424 to R12 204 ha^{-1}, and the treatments had a similar IRR of 5%. The tested treatments (T2 and T3) had a LEV of R1 232 and R4 780 ha^{-1} below the control treatment and were R3 139 and R5 706 more expensive respectively. The application of zero fertiliser at mid-rotation was much more profitable than the application of the two tested fertiliser yields. Considering that, mid-rotation fertiliser reduced LEV by R1 232 ha^{-1} and the tested treatments had high treatment cost per tonne values indicating that the rotation volume could not compensate for the treatment costs.

The generic DCF model had a higher LEV in comparison to the FR9 treatments, all the treatments had a LEV lower than the land value (R13 568) and the NPVs were below zero proving the investment project could not be accepted. Further results are described by Table 4.9.

Table 4.9: The DCF model results for FR9 research trial treatments, including the total treatment cost and a description of the tested treatments.

Treatment	Treatment details	Treatment cost (Rands)	Rot.Vol (tons ha^{-1})	Treatment cost per additional tonne (R ton-1)	LEV (R ha^{-1})	NPV (R ha^{-1})	EAI (R ha^{-1})	IRR (%)	BCR
T1	0 [Control] Zero application of fertiliser	0	150		**12 204**	**-646**	**-38**	**5**	**1.29**
T2	NPK [N + P + K] Applied 10.3 years after planting	3 139	156	561	**10 972**	**-1231**	**-71**	**5**	**1.26**
T3	NPK+ [N + P + K + Ca + Mg + B + Cu + Zn] Applied 10.3 years after planting	5 706	155	1189	**7 424**	**-2 912**	**-169**	**5**	**1.23**

Results marked in orange are below the LEV of the control treatment.

4.3.2.10. DCF model results for FR10 research trial

The LEV ranged from R19 293 to R94 894 ha^{-1}, and the treatments IRR differed from 6 to 15%. The application of T4 costed R818 more than the control treatment, but T4 increased volume by 93% and increased LEV by R75 605 ha^{-1}. Similarly, the IRR increased from 6 to 15% indicating T4 as the most profitable treatment. Further results are described by Table 4.10.

All the treatments had higher LEV in comparison to the generic DCF model and the land value. Therefore, the investment project was acceptable and more profitable than the generic DCF model.

Table 4.10: The DCF model results for FR10 research trial treatments, including the total treatment cost and a description of the tested treatments.

Treatment	Treatment details	Treatment cost (Rands)	Rot.Vol (tons ha^{-1})	Treatment cost per additional tonne (R ton-1)	LEV (R ha^{-1})	NPV (R ha^{-1})	EAI (R ha^{-1})	IRR (%)	BCR
T1	0 [Control] Zero application of fertiliser	0	106		19 293	1 995	116	6	1.25
T2	Agrofert 40 Kg N ha^{-1} Applied 1 year after planting	486	145	12	49 201	12 414	720	10	1.39
T3	Agrofert 40 Kg N ha^{-1} + 40 Kg N ha^{-1} Applied 1 year after planting	972	178	13	74 198	21 124	1 226	13	1.49
T4	Agrofert 80 Kg N ha^{-1} Applied 1 year after planting	818	204	8	94 894	28 334	1 644	15	1.55
T5	Agrofert 80 Kg N ha^{-1} + 80 Kg N ha^{-1} Applied 1 year after planting	1 636	175	24	69 837	19 604	1 138	13	1.47
T6	Humac 40 Kg N ha^{-1} Applied 1 year after planting	486	148	11	51 656	13 270	770	11	1.40
T7	Humac 40 Kg N ha^{-1} + 40 Kg N ha^{-1} Applied 1 year after planting	972	181	13	76 653	21 979	1 275	13	1.49
T8	Humac 80 Kg N ha^{-1} Applied 1 year after planting	818	159	15	59 295	15 931	924	12	1.43
T9	Humac 80 Kg N ha^{-1} + 80 Kg N ha^{-1} Applied 1 year after planting	1 636	172	25	67 382	18 749	1 088	12	1.46

Results marked in green are above the LEV of the control treatment.

4.3.3. Sensitivity Analyses Results for FR Research Trials

Sensitivity analyses results indicate that when an optimistic (3.5 and 4.5%) real discounted rate is used the land expectation value (LEV) increases. Conversely, at a pessimistic (6.5 and 7.5%) real discounted rates the LEV decreases.

Sensitivity results for the FR6 research trial indicated that the control treatment LEV becomes unacceptable at a pessimistic real discounted rate of 7.5% [LEV (R11 690) < Land value (R13 568)]. Furthermore, for FR9 research trial, the sensitivity results indicate that only at optimistic (4.5%) real rates does the investment project (control treatment) becomes acceptable [LEV (R21 108) > Land value (R13 568)]. Conversely, at current (5.5%) and pessimistic real discounted rates the investment project is unacceptable.

4.3.4. Overview of financial analyses results for FR research trials

Site conditions and productivity differ, therefore, there are no individual management practices or regimes that are suitable for all sites (Jones *et al*., 2010). For example, both FR1 and FR2 research trials had similar management practices: (i) harvesting residue burnt prior to planting, (ii) site kept weed free until canopy closure, (iii) fertiliser applied at planting in a ring around each tree, (iv) similar tested treatments, (v) *E. grandis x urophylla* planted on both sites, and (vi) a trial duration of 6.5 years. However, FR1 research trial was established on a low fertility site (red meso-tropic soils), while FR2 on a high fertility (dark top soil sands) site.

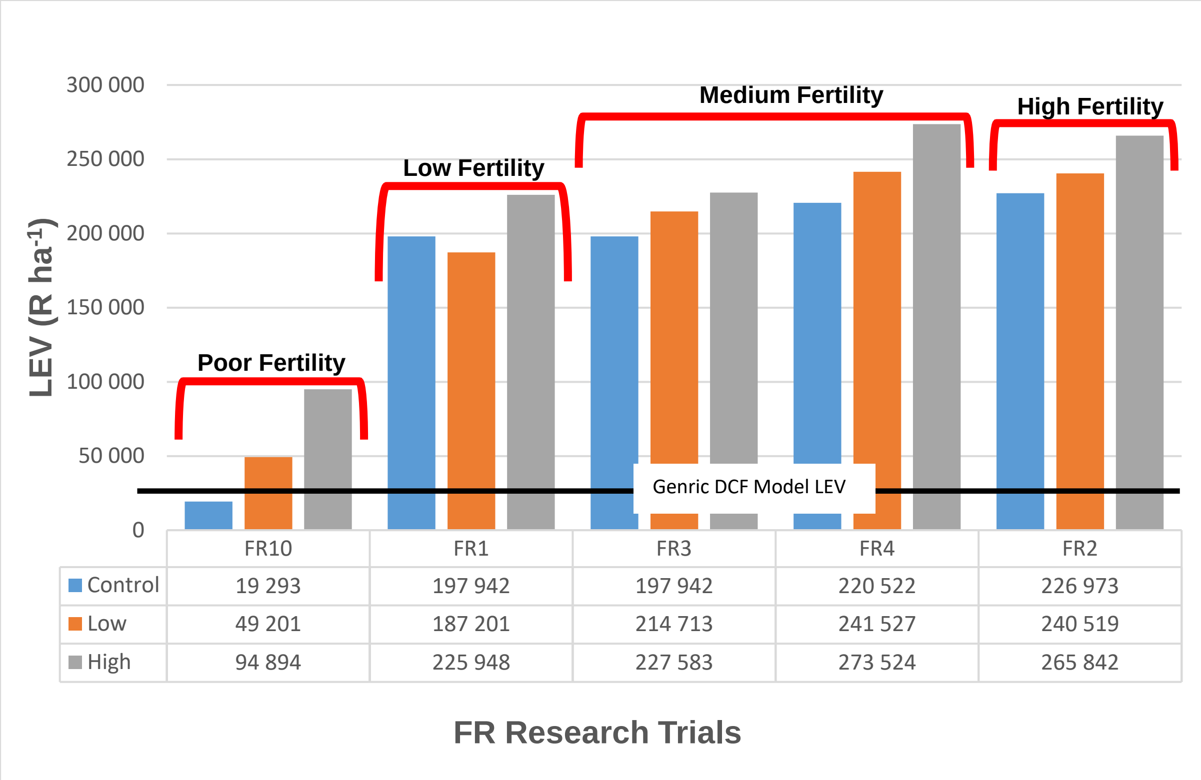
The average rotation volume (Rot.Vol) for FR2 was 13% higher than FR1, illustrating the type of effect site has on management regimes. Thus, financial returns determined from research results should be regarded as site specific financial gains.

Only two of the FR research trials were located in the northern part of the coastal region of Zululand and the rest of the trials were established in coastal Zululand region. However, trials in the latter region were established on low, medium and high fertility soils. The coastal Zululand region is regarded as having sandy soils with low organic matter, however, the fertility and the potential nutrient supply of the soil differs (du Toit and Oscroft, 2003).

Figure 4.3 indicates the profitability of FR research trials on poor, low, medium and high fertility soils, based on the land expectation values (LEVs). The LEV allows us to compared forest investment project (or management practices) with different time periods. Returns on high and low fertility sites are generally expected to be higher than low productivity sites. Financial gains (LEV) for high fertility sites were higher than low and poor fertility site but, the financial returns for the application of on-site specific fertiliser recommendations were higher on the poor fertility site (FR10). The highest determined LEV for FR10 (low fertility) was 79.6% more than the control, while on medium (FR3) and high fertility (FR2) sites the LEV was only 19 and 14% more than the control treatment. In addition, high and medium fertility sites were 64 and 58% more profitable than the poor fertility site research trial.

All the research trials indicated in Figure 4.3 accounted for an increase of inputs costs (fertiliser) ranging from R12 099 ha^{-1} to R27 157 ha^{-1}, which is significantly higher in comparison to the initial treatments cost ranging from R799 ha^{-1} to R1 582 ha^{-1}. Thus, the most profitable treatments (in terms of LEVs) for FR1, FR2, FR3, FR4 and FR10 are financially cost effect and the increase in yield (tons ha^{-1}) significantly justified the investments made at re-establishment. Along similar lines, Jones *et al*. (2010) mentioned that for an increase in re-establishment intensity to be financially cost-effective, the increase in incremental growth should be enough to justify the additional investment.

Furthermore, Figure 4.3 also indicates that the LEVs of these trials were higher than the generic DCF model LEV. However, the control treatment for FR10 research was below the generic DCF model LEV, but the lowest tested treatment was higher.



	FR10	FR1	FR3	FR4	FR2
Control	19 293	197 942	197 942	220 522	226 973
Low	49 201	187 201	214 713	241 527	240 519
High	94 894	225 948	227 583	273 524	265 842

Figure 4.3: LEVs for FR10, FR1, FR3, FR4 and FR2 research trials. Presented in ascending order based on the fertiliser of the site. Further provides the lowest, highest and control treatment LEVs.

Mid-rotation on-site fertiliser recommendation research trials (FR5, FR6, FR7, FR8 and FR9) were carried out in inland and coastal Zululand regions. The application of fertiliser was implemented between 3.6 years after planting (FR7) and 10.3 years after planting (FR9). Furthermore, the trial duration or rotation age ranged from 6.8 years for FR5 and 12 years for FR9. Research trials FR5, FR6 and FR7 were established on soils with low clay content, low base status and low organic content, thus associated with low fertility soils. On the other hand, FR8 and FR9 were established on soils with a medium to high clay and organic carbon content, and base status, therefore the site associated with medium to high fertility soils.

Financial results for mid-rotation trials indicated no financial gains (no profitability) for all the tested treatments compared to the control treatment. Equally important, site with low and medium to high fertility had similar financial returns to mid-rotation fertilisation. However, the sites referred to as medium to high fertility had a lower LEV than low fertility sites, this is further indicated by Figure 4.4. For instance, the LEV for FR5 control treatment was 13 times higher than FR9 research trial control. Although FR5 was established on a subtropical climatic zone with fast growing *E. grandis x E.*

camaldulensis and FR9 established on a warm-temperate climatic zone site with *E. grandis x E. nites*. In addition, FR9 had a longer rotation of 12 years compared to a 6.8-year rotation for FR5 research trial. Accordingly, this could be the reason for a lower LEV for FR9 in comparison to FR5.

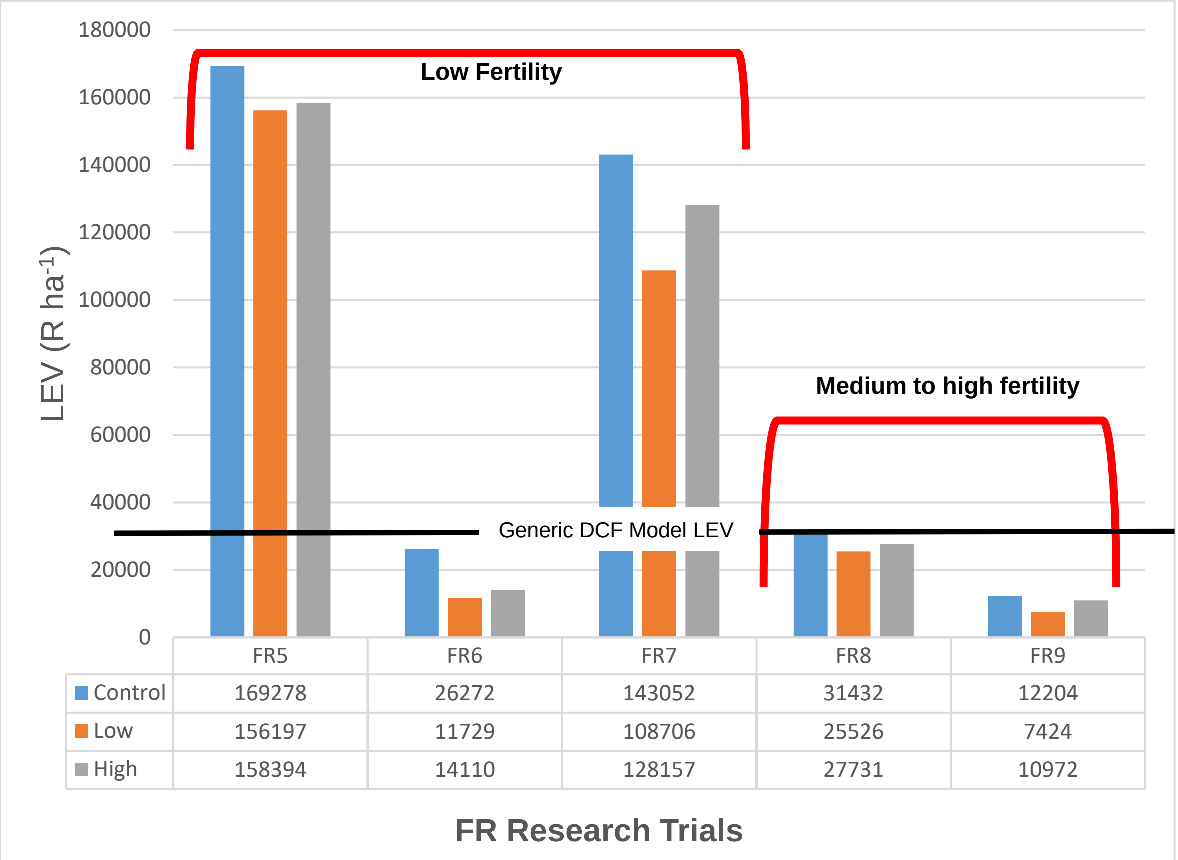


Figure 4.4: LEVs for FR5, FR6, FR7, FR8 and FR9 research trials. Presented in ascending order based on the fertiliser of the site. Further provides the lowest, highest and control treatment LEVs.

Figure 4.4 further indicates that FR6 and FR9 research LEVs were lower than the generic DCF model LEV and for FR8 research the control LEV was slightly higher than the generic DCF model LEV but the tested treatments were lower. On the other hand, FR5, FR6 and FR7 established on low fertility sites had higher LEVs in comparison to generic DCF model LEV.

These observations are in line with findings of Titshall (2013), who concluded that there was no significant response in the application of fertiliser at mid-rotation age. Therefore, there were no financial gains resulting from the application of fertiliser at mid-rotations. Thus, the added management intensity cannot be justified due to low incremental growth from tested treatments.

4.4. FOREST MANAGEMENT: RESIDUE MANAGEMENT

4.4.1. Meta-Analyses Framework Results for RM Research Trials

The first of the residue management (RM) trials investigated the effect of harvesting compaction as main treatment factor and the application of fertiliser at planting was the split factor treatment. Second RM trials were established after the RM3 research trial on the same site in eTeza, the RM2 treatment factors were burning vs no burning. For RM3 there were 3 treatment factors imposed on the trial, (i) burning vs no burning, (ii) fertiliser vs no fertiliser and (iii) three pitting preparation techniques. The last residue management trial investigated the effect of compaction and residue management as main treatment factors.

Fertiliser was applied two days after planting, in parallel grooves on either side of the stem for RM1 treatments, and RM2 fertiliser was applied three weeks after planting in a buried ring 0.3 m away from the tree. Fertiliser was applied at two intervals for RM3 firstly at planting then again after 6 months and no fertiliser was applied in the last trial (RM4).

Individual tree volume was determined according to volume equations for RM1 and RM4, and for RM2 and RM3 treatment volume was determined by merchantable volume equations at rotation age. There were reported significant difference in volume for tested treatment for RM2 research trial only. For the other three trials, there were no significant differences in volume reported for the tested treatments.

Residue management (RM2) had the highest TI (20%) and the highest average TI (7%), all the treatments for RM3 had TI's of below 0% the highest TI for RM1 was at 8% and an average treatment improvement of 2%. As illustrated in Figure 4.5, there was no control treatment for RM4 therefore, treatment improvement was not calculated.

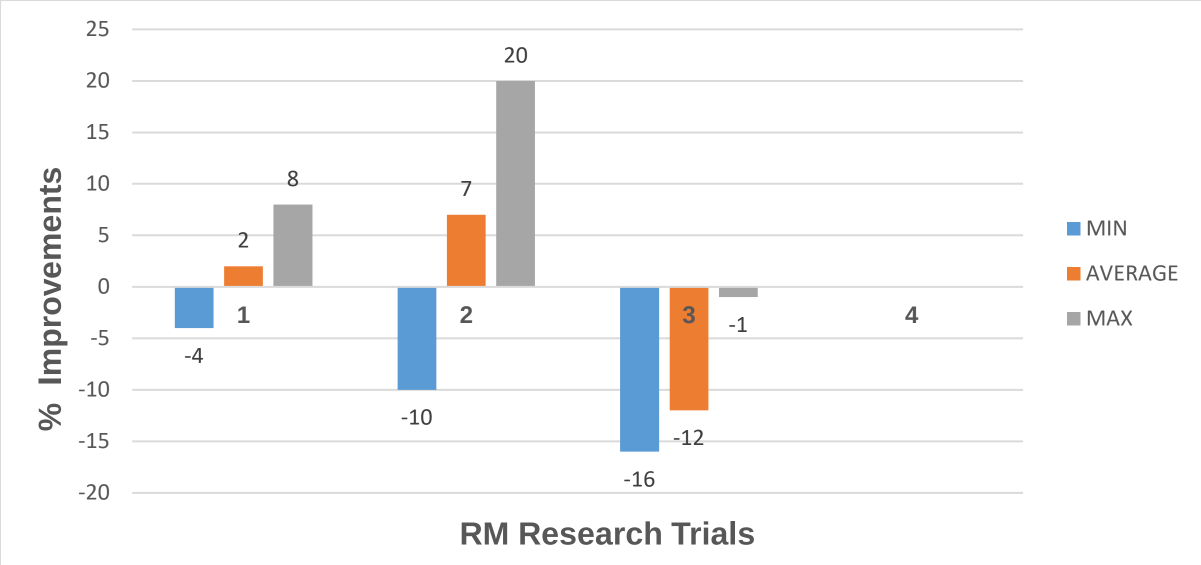


Figure 4.5: The lowest, average and highest treatment improvements (%) relative to the control treatment for the RM research trials.

4.4.2. Financial Analyses Results for RM Research Trials

Financial analyses were carried out for all four FM research trials; and results are presented based on the different tested treatments per trial as follows:

4.4.2.1. DCF model results for RM1 trial

The LEV ranged from R135 970 to R161 927 ha^{-1}, and the treatments IRR differed slightly from 20 to 23%. Furthermore, the application of T8 costed R776 more than the control treatment, but T8 increased LEV by R8 900 ha^{-1} based on the control treatment. Assuming all harvesting costs were the same, T4 was the most profitable treatment from the four harvesting treatments. Further results are presented by Table 4.11. Additionally, all the tested treatments had higher LEVs than the generic DCF model LEV (R30 980) and land value (R13 568), thus, the investment project could be regarded as acceptable.

Table 4.11: The DCF model results for RM1 research trial treatments, including the total treatment cost and a description of the tested treatments.

Treatment	Treatment details	Treatment cost (Rands)	Rot.Vol (tons ha^{-1})	LEV (R ha^{-1})	NPV (R ha^{-1})	EAI (R ha^{-1})	IRR (%)	BCR
T1 [MB]	Manual felling + Broadcast At harvesting and residue management after harvesting	128 ton^{-1}	224	**144 704**	**40 988**	**2 378**	**21**	**2.4**
T2 [MW]	Manual felling + Windrowed At harvesting and residue management after harvesting	128 ton^{-1}	224	**144 704**	**40 988**	**2 378**	**21**	**2.4**
T3 [TH]	Tracked harvester + Semi-windrowed At harvesting and residue management after harvesting	128 ton^{-1}	215	**135 970**	**38 258**	**2 220**	**20**	**2.4**
T4 [WH]	Wheeled harvester At harvesting and residue management after harvesting	128 ton^{-1}	242	**161 927**	**46 372**	**2 691**	**23**	**2.5**
T5 [F0]	No fertiliser [Control] Zero application of fertiliser	0	224	**144 704**	**40 988**	**2 378**	**21**	**2.4**
T6 [F1]	233 g $tree^{-1}$ [45 g $tree^{-1}$ N + 18 g $tree^{-1}$ P] Applied two days after planting	675	229	**146 887**	**41 671**	**2 418**	**21**	**2.42**
T7 [F2]	155 g $tree^{-1}$ [30 g $tree^{-1}$ N + 12 g $tree^{-1}$ P] Applied two days after planting	501	233	**151 861**	**43 225**	**2 508**	**22**	**2.44**
T8 [F3]	300 g $tree^{-1}$ [45 g $tree^{-1}$ N + 30 g $tree^{-1}$ P] Applied two days after planting	776	236	**153 604**	**43 770**	**2 540**	**22**	**2.44**
T9 [F4]	200 g $tree^{-1}$ [30 g $tree^{-1}$ N + 20 g $tree^{-1}$ P] Applied two days after planting	569	229	**147 228**	**41 777**	**2 424**	**21**	**2.42**

Results marked in orange are below the LEV of the control treatment, while those in green are above the control treatment LEV.

4.4.2.2. DCF model results for RM2 trial

Land expectation value ranged from –R3 776 to R16 778 ha^{-1}, and the treatments IRR differed from 2 to 6%. The application of T3 costed R629 more than control treatment, but T3 increased volume by 20% and increased LEV by R12 348 ha^{-1}. Similarly, the IRR increased from 4 to 6% indicating T3 as the most profitable treatment. Furthermore, control, T2 and T4 had LEVs lower than the land value (R13 568) and IRRs were lower than the real discounted rate (5.5%). Thus, these investment projects could be regarded as unacceptable. These results are further illustrated by Table 4.12.

All the treatments had LEVs lower than the generic DCF model and in this regard the model was more profitable.

Table 4.12: The DCF model results for RM2 research trial treatments, including the total treatment cost and a description of the tested treatments.

Treatment	Treatment details	Treatment cost (Rands)	Rot.Vol (tons ha^{-1})	LEV (R ha^{-1})	NPV (R ha^{-1})	EAI (R ha^{-1})	IRR (%)	BCR
T1	No burn + No Fertiliser [Control]	0	77	**4 430**	**-2 856**	**-166**	**4**	**1.47**
T2	Burnt + No Fertiliser Residue burn prior to planting	321	69	**-3 776**	**-5 421**	**-315**	**2**	**1.37**
T3	No burn + Fertiliser Fertiliser applied three weeks after planting	629	92	**16 778**	**1 003**	**58**	**6**	**1.60**
T4	Burnt + Fertiliser Residue burn prior to planting and fertiliser applied three weeks after planting	950	84	**8 572**	**-1 562**	**-91**	**5**	**1.51**

Results marked in orange are below the LEV of the control treatment, while those in green are above the control treatment LEV.

4.4.2.3. *DCF model results for RM3 trial*

The LEV ranged from R39 312 to R67 167 ha^{-1}, and the treatments IRR differed from 9 to 13%. The ripping and mechanical pitting treatments had the lowest treatment costs, while manual pitting treatments were the most expensive. However, the manual pitting treatments had a higher LEV when coupled with other treatment factors (burning vs. no burning and fertiliser vs. no fertiliser).

The application of zero fertiliser, no burning of residue prior to planting and manual pitting technique was much more profitable than tested treatments. Furthermore, application of other treatment factors could reduce LEV and IRR by up to R27 855 ha^{-1} and 4% respectively. All the tested treatments had higher LEVs than the generic DCF model LEV and land value, therefore, the investment project could be regarded as acceptable. Further results are described in Table 4.13.

Table 4.13: The DCF model results for RM3 research trial treatments, including the total treatment cost and a description of the tested treatments.

Treatment	Treatment details	Treatment cost (Rands)	Rot.Vol (tons ha^{-1})	LEV (R ha^{-1})	NPV (R ha^{-1})	EAI (R ha^{-1})	IRR (%)	BCR
T1	No burn + Manual Pitting + No Fertiliser [Control]	0	166	**67 167**	**18 674**	**1 084**	**13**	**1.47**
T2	No burn + Manual pitting + Fertiliser Fertiliser applied at planting and again 6 months after planting	1 258	149	**50 052**	**12 711**	**738**	**11**	**1.39**
T3	No burn + Mechanical pitting + No fertiliser	-550	150	**55 857**	**14 733**	**855**	**12**	**1.43**
T4	No burn + Mechanical pitting + Fertiliser Fertiliser applied at planting and again 6 months after planting	708	164	**63 292**	**17 324**	**1 005**	**12**	**1.45**
T5	No burn + Ripping + No fertiliser	-1 250	145	**54 183**	**14 150**	**821**	**11**	**1.42**
T6	No burn + Ripping + Fertiliser Fertiliser applied at planting and again 6 months after planting	8	146	**51 185**	**13 106**	**760**	**11**	**1.40**

Treatment	Treatment details	Treatment cost (Rands)	Rot.Vol (tons ha^{-1})	LEV (R ha^{-1})	NPV (R ha^{-1})	EAI (R ha^{-1})	IRR (%)	BCR
T7	Burnt + Manual pitting + No fertiliser Residue burnt prior to planting	321	133	40 468	9 372	544	9	1.36
T8	Burnt + Manual pitting + Fertiliser Residue burnt prior to planting and fertiliser applied at planting and again 6 months after planting	1 579	137	39 312	8 969	520	9	1.35
T9	Burnt + Mechanical pitting + No fertiliser Residue burnt prior to planting	-229	163	65 370	18 048	1 047	13	1.46
T10	Burnt + Mechanical pitting + Fertiliser Residue burnt prior to planting and fertiliser applied at planting and again 6 months after planting	1 029	142	45 187	11 016	639	10	1.37
T11	Burnt + Ripping + No fertiliser Residue burnt prior to planting	-929	140	49 580	12 547	728	11	1.40
T12	Burnt + Ripping + Fertiliser Residue burnt prior to planting and fertiliser applied at planting and again 6 months after planting	329	140	45 354	11 074	643	10.	1.38

Results marked in orange are below the LEV of the control treatment.

4.4.2.4. DCF model results for RM4 trial

The LEV ranged from R62 895 to R64 879, and the treatments had the same IRR of 12%. Assuming all harvesting costs (compaction treatments) are the same, T1 and T6 were the most profitable. However, the profitability was insignificant as the minor difference in LEV costs. Further results are presented by Table 4.14.

In addition, all treatments had higher LEVs in comparison to the generic DCF model and the land value, proving that the investment project was acceptable.

Table 4.14: The DCF model results for RM4 research trial treatments, including the total treatment cost and a description of the tested treatments.

Treatment	Treatment details	Treatment cost (Rands)	Rot.Vol (tons ha^{-1})	LEV (R ha^{-1})	NPV (R ha^{-1})	EAI (R ha^{-1})	IRR (%)	BCR
T1	Low Compaction At harvesting	128 ton^{-1}	157	**64 879**	**17 877**	**1 037**	**12**	**1.46**
T2	Moderate Compaction At harvesting	128 ton^{-1}	156	**64 218**	**17 646**	**1 024**	**12**	**1.46**
T3	High Compaction At harvesting	128 ton^{-1}	156	**64 218**	**17 646**	**1 024**	**12**	**1.46**
T4	Residue Broadcast Residue management after harvesting	128 ton^{-1}	156	**64 218**	**17 646**	**1 024**	**12**	**1.46**
T5	Residue Windrow Residue management after harvesting	128 ton^{-1}	157	**64 879**	**17 877**	**1 037**	**12**	**1.46**
T6	Residue Removed Residue management after harvesting	128 ton^{-1}	154	**62 895**	**17 185**	**997**	**12**	**1.45**

Results are not marked as there was no control treatment.

4.4.3. Sensitivity Analyses Results for RM Research Trials

Sensitivity analyses results indicate that when an optimistic (3.5 and 4.5%) real discounted rate is used the land expectation value (LEV) increases. Conversely, at a pessimistic (6.5 and 7.5%) real discounted rates the LEV decreases.

For RMR2 research trial, the sensitivity results indicated that the control treatment LEV only becomes acceptable at an optimistic real discounted rate of 3.5% [LEV (R16 459) > Land value (R13 568)], while treatment 4 becomes acceptable at an optimistic real discounted rate of 4.5% [LEV (R14 541) > Land value]. However, at optimistic real discounted rates treatment 2 still had a lower LEV (R2 970 and - R1 181 at 3.5 and 4.5% respectively) compared to the land value. Furthermore, treatment 3 LEV only becomes unacceptable at pessimistic real discounted rates.

4.4.4. Overview of financial analyses results for RM research trials

Residue management (RM4) research trials were established on the same site after RM1 was harvested (end of trial). Treatment factors tested included a combination of harvesting and residue management, as well as five fertiliser treatments (including control) for RM1. While the succeeding trial (RM4) only had a combination of compaction (harvesting) and residue management treatment factors. Both trials had no significant differences in rotation volume, including the five fertiliser treatment tested in RM1.

Furthermore, research trials (RM2 and RM3) were established to determined changes in productivity between successive rotations. The residue management two (RM2) research trial was established on the same site, succeeding RM3. The two research trials differed only with one treatment factor, RM3 had an additional pitting technique (manual, mechanical and ripping) treatment factor.

The average treatment rotation volume (Rot.Vol) for RM2 and RM3 were 80.6 and 147.7 ton ha^{-1} respectively. Financial returns based on the LEV also differed significantly with the highest tested treatment LEVs at R16 778 and R65 370 ha^{-1} for RM2 and RM3 respectively. Furthermore, RM2 treatment (including control) had LEVs below both the generic DCF model LEV and the land value (R13 568), therefore, invests projects in this site with these treatment can be regarded as unacceptable based on LEV. However, only treatment three of the RM2 research trial had an LEV higher than the land value, thus, investment into this site with treatment three can be regarded as acceptable.

Along similar lines with RM1 and RM4, site productivity and financial returns declined significantly between the two succeeding research trials. Likewise, RM2 and RM3 indicate a decline in site productivity (based on yields at rotation) and financial returns. Considering that, the latter research trials had a similar treatment factor were either harvest residue was burned prior to planting or harvest residue was not burned before planting.

4.5. FOREST MANAGEMENT: VEGETATION AND COPPICE MANAGEMENT

4.5.1. Meta-Analyses Framework Results for VCM Research Trials

Vegetation management research trials main treatment factors were weed control techniques, ranging from manual, chemical and cover-crops. The coppice management research trials main treatment factors were re-establishment using coppice management ranging from the timing of reduction operations and the control of secondary coppice regrowth. Furthermore, VCM1, VCM4, VCM5 and VCM6 had application of fertiliser as a split-treatment factor.

Individual tree volume treatments were determined according to volume equations for VMC11 trial and then for VCM1, VCM3, VCM4, VCM5 and VCM6 merchantable volume per treatment were determined. However, volume was not reported for VCM2, VCM7, VCM8, VCM9 and VCM10 research trials.

There were significant differences in volume reported for tested treatment for VCM1, VCM3 and VCM4 research trials. On the other hand, there was no significant difference in volume reported for tested treatments for the rest of research trials. However, for VCM7 research trial volume at rotation age was not reported, but there were significant difference reported in the total number of operations carried out for tested treatments.

Volume treatment improvements (TI) were only determined for VCM1, VCM3, VCM4 and VCM11. The other research trials had not reported rotation volume (as seen in Figure 4.6). The highest TI for VCM11 was 8% with an average of 4%, which resemble the reported insignificant difference in volume at the rotation. On the other hand, VCM3 and VCM4 had maximum TI's of 41 and 63%, and average TI's of 26 and 35% respectively. Furthermore, VCM1 also had significant treatment improvements reported, as illustrated in Figure 4.5, the lowest TI was 5% and an average of 17% and the highest treatment improvement was 29%.

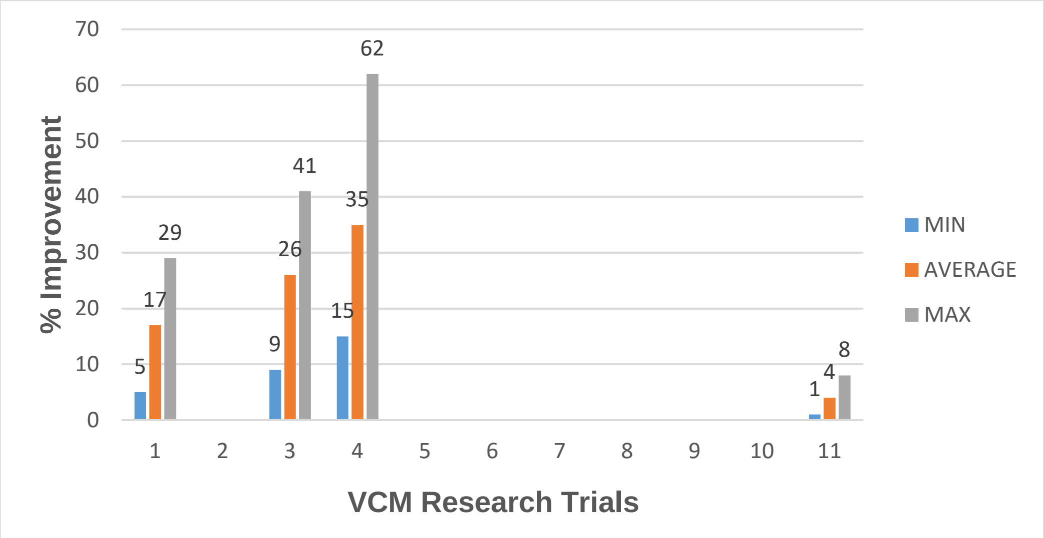


Figure 4.6: The lowest, average and highest treatment improvements (%) relative to the control treatment for the VCM research trials.

4.5.2. Financial Results for VCM Research Trials

Financial analyses were carried out for ten of the VCM research trials, VCM10 trial was not modelled. Reason being, the trial had not reported rotation volume and tested treatments costs could not be quantified. The following results are presented based on the different tested treatments per research trial:

4.5.2.1. DCF model results for VCM1 trial

Land expectation value ranged from R57 190 to R83 675 ha^{-1}, and the treatments IRR differed slightly from 12 to 15%. The application of T2 costed R3 001 more than the control treatment, but T2 increased rotation volume by 29% and increased LEV by R26 485 ha^{-1}. Similarly, the IRR increased from 12 to 15% indicating T2 as the most profitable treatment. Furthermore, T4 had the lowest treatment cost per additional tonne, thus, it could be regarded as the most cost effective treatment. Results are indicated in Table 4.15.

All the treatments had higher LEVs than the generic DCF model LEV (R30 980) and the land value (R13 568). Thus, the investment project was acceptable.

Table 4.15: The DCF model results for VCM1 research trial treatments, including the total treatment cost and a description of the tested treatments.

Treatment	Treatment details	Treatment cost (Rands)	Rot.Vol (tons ha^{-1})	Treatment cost per additional tonne (R ton^{-1})	LEV (R ha^{-1})	NPV (R ha^{-1})	EAI (R ha^{-1})	IRR (%)	BCR
T1	Weedy check + Method none [Control] Fertiliser applied at planting	627	128		**57 190**	**13 635**	**791**	**12**	**1.41**
T2	Weedy-free check + Manual weed control [Manual weeding x3] Fertiliser applied at planting	3 629	166	79.8	**83 675**	**21 913**	**1271**	**15**	**1.48**
T3	Cowpeas single row 1.5 m from tree rows cowpea cover-crop + manual [x2] Fertiliser applied at planting	2 080	134	246.2	**58 379**	**14 006**	**813**	**12**	**1.41**
T4	Cowpeas singe row 1.5 m from tree + herbicide combination of metolachlor + paraquate was sprayed in inter-row after cowpeas cover-crop + chemical + manual Fertiliser applied at planting	2 417	158	61.3	**79 095**	**20 481**	**1 188**	**14**	**1.48**
T5	Cowpeas planted in a double row 1 m from tree rows Cowpeas cover-crop + manual Fertiliser applied at planting	1 954	143	93	**66 622**	**16 583**	**962**	**13**	**1.44**
T6	Cowpeas planted in a double row 1 m from tree rows + herbicide combination of metolachlor + paraquate was sprayed in the inter-row after the cowpeas were planted Cowpeas cover-crop + chemical + manual Fertiliser applied at planting	2 445	154	72	**75 264**	**19 284**	**1 119**	**14**	**1.46**

Results marked in green are above the LEV of the control treatment.

4.5.2.2. *DCF model results for VCM2 trial*

The LEV ranged from R25 952 to R34 845 ha^{-1}, and the treatments IRR differed slightly from 7 to 9%. There was a LEV difference of R8 893 ha^{-1} between the most expensive treatment (T1) and the least (T6). Even though, there was no significant differences reported in Rot.Vol between treatments tested. The financial results indicated that the cheaper treatment 6 to be more profitable. Further results are presented in Table 4.16.

The tested treatments were higher than the land value thus the investment project was acceptable. However, treatments T1, T2 and T3 had lower LEVs compared to the generic DCF model LEV and therefore less profitable.

Table 4.16: The DCF model results for VCM2 research trial treatments, including the total treatment cost and a description of the tested treatments.

Treatment	Treatment details	Treatment cost (Rands)	Rot.Vol (tons ha^{-1})	LEV (R ha^{-1})	NPV (R ha^{-1})	EAI (R ha^{-1})	IRR	BCR
T1	Imposed at 2 years + kept weed free for 7 years + 0 year weedy state before weeding	5 178	109	**25 952**	**3 871**	**225**	**7**	**1.24**
T2	Imposed at 3 years + kept weed free for 6 years + 1 year weedy state before weeding	4 438	109	**27 392**	**4 321**	**251**	**8**	**1.25**
T3	Imposed at 4 years + Kept weed free for 5 years + 2 year weedy state before weeding	3 698	109	**29 407**	**4 951**	**287**	**8**	**1.27**
T4	Imposed at 5 years + Kept weed free for 6 years + 3 years weedy state before weeding	2 959	109	**31 318**	**5 548**	**322**	**8**	**1.28**
T5	Imposed at 6 years + Kept weed free for 7 years + 4 years weedy state before weeding	2 219	109	**33 128**	**6 114**	**355**	**9**	**1.29**
T6	Imposed at 7 years + Kept weed free for 8 years + 5 years weedy state before weeding	1 479	109	**34 845**	**6 650**	**386**	**9**	**1.30**

Results are not marked as there was no control treatment.

4.5.2.3. *DCF model results for VCM3 trial*

The LEV ranged from R82 013 to R137 396 ha^{-1}, and the treatments IRR differed slightly from 15 to 20%. Furthermore, the application of T4 costed R1 478 more than the control treatment, but T4 increased rotation volume by 41% and increased LEV by R55 383 ha^{-1}. In addition, the IRR increased from 15% to 20% indicating T4 as the most profitable treatment. Similarly, T4 had the lowest treatment cost per additional tonne and could also be regarded as the most cost effective treatment.

All the treatments had higher LEVs than the generic DCF model LEV and the land value. Thus, the investment project was acceptable, further results are described by Table 4.17.

Table 4.17: The DCF model results for VCM3 research trial treatments, including the total treatment cost and a description of the tested treatments.

Treatment	Treatment details	Treatment cost (Rands)	Rot.Vol (tons ha^{-1})	Treatment cost per additional tonne (R ton^{-1})	LEV (R ha^{-1})	NPV (R ha^{-1})	EAI (R ha^{-1})	IRR (%)	BCR
T1	No weed control; Burnt + Weedy [Control] Residue burnt prior to planting	321	156		**82 013**	**21 393**	**1 241**	**15**	**1.50**
T2	Complete vegetation control with glyphosate (4l ha^{-1}) when required; Burnt + Weed free Residue burnt prior to planting	2 119	216	30.0	**132 926**	**37 307**	**2 165**	**20**	**1.62**
T4	Complete vegetation control with glyphosate (4l ha^{-1}) when required; Unburnt + Weed free	1 799	219	23.2	**137 396**	**38 704**	**2 246**	**20**	**1.63**
T5	Control of all vegetation for 1 m on either side of the tree row with glyphosate (4l ha^{-1}) when required; Unburnt + 2 m row weeding`	2 799	213	43.3	**128 602**	**35 955**	**2 086**	**19**	**1.60**

Results marked in green are above the LEV of the control treatment.

4.5.2.4. DCF model results for VCM4 trial

The LEV ranged from R40 341 to R93 227 ha^{-1}, and the treatments IRR differed slightly from 10% to 16%. The application of T2 costed R4 629 more than the control treatment, but T2 increased rotation volume by 62% and increased LEV by R52 886 ha^{-1}. Similarly, the IRR increased from 10 to 16% indicating T2 as the most profitable treatment. Treatment 2 also had the lowest treatment cost per additional tonne and could be regarded as the most cost effective treatment.

All the treatments had higher LEVs than the generic DCF model LEV and the land value. Thus, the investment project was acceptable, further results are presented in Table 4.18.

Table 4.18: The DCF model results for VCM4 research trial treatments, including the total treatment cost and a description of the tested treatments.

Treatment	Treatment details	Treatment cost (Rands)	Rot.Vol (tons ha^{-1})	Treatment cost per additional tonne (R ton^{-1})	LEV (R ha^{-1})	NPV (R ha^{-1})	EAI (R ha^{-1})	IRR (%)	BCR
T1	No weed control [Control] Fertiliser applied at planting	627	110		**40 341**	**8 368**	**486**	**10**	**1.34**
T2	Weed free; Manual Fertiliser applied at planting	4 629	179	58	**93 227**	**24 898**	**1 445**	**16**	**1.50**
T3	Weed free; Chemical Fertiliser applied at planting	4 225	153	85	**69 679**	**17 538**	**1 018**	**13**	**1.43**
T8	Cover-crop with weeding to establish; Cowpea; Fertilised at planting Fertiliser applied at planting	2 108	126	93	**50 826**	**11 645**	**676**	**11**	**1.38**

Results marked in green are above the LEV of the control treatment.

4.5.2.5. DCF model results for VCM5 trial

The LEV ranged from R55 102 to R71 483 ha^{-1}, and the treatments IRR differed slightly from 12 to 15%. Even though, there were no significant differences in Rot.Vol between treatments tested. Using the treatment mean Rot.Vol indicated that the cheaper treatment (T1) to be more profitable. Further results are indicated in Table 4.19.

All the treatments had higher LEVs than the generic DCF model LEV and the land value. Thus, the investment project was acceptable for all treatments. Furthermore, the re-establishment with coppice could be seen to be more profitable than re-establishment with planting based on the generic DCF model LEV.

Table 4.19: The DCF model results for VCM5 research trial treatments, including the total treatment cost and a description of the tested treatments

Treatment	Treatment details	Treatment cost (Rands)	Rot.Vol (tons ha^{-1})	LEV (R ha^{-1})	NPV (R ha^{-1})	EAI (R ha^{-1})	IRR (%)	BCR
T1	2 m + 7 m; No control; Weedy	667	132	**71 483**	**18 102**	**1 050**	**15**	**1.49**
T2	2 m + 7 m; No control; Weed control	3 665	132	**63 126**	**15 490**	**899**	**13**	**1.43**
T3	2 m + 7 m; Manual when 0.75 m high; Weedy	3 001	132	**64 957**	**16 062**	**932**	**14**	**1.44**
T4	2 m + 7 m; Manual when 0.75 m high; Weed control	4 335	132	**61 217**	**14 893**	**864**	**13**	**1.42**
T5	2 m + 7 m; Sprayed with glyphosate at 0.6% when 0.75 m high; Weedy	5 463	132	**59 750**	**14 435**	**838**	**13**	**1.41**
T6	2 m + 7 m; Sprayed with glyphosate at 0.6% when 0.75 m high; Weed control	6 531	132	**55 102**	**12 982**	**753**	**12**	**1.38**

Results are not marked as there was no control treatment.

4.5.2.6. DCF model results for VCM6 trial

The LEV ranged from R115 535 to R121 431 ha^{-1}, and the treatments IRR differed insignificantly from 18 to 19%. Using the treatment mean Rot.Vol indicated that the cheaper treatment (T3) to be more profitable. Further results described by Table 4.20.

All the treatments had higher LEVs than the generic DCF model LEV and the land value. Thus, the investment project was acceptable for all treatments. Furthermore, the re-establishment with coppice could be seen to be more profitable than re-establishment with planting based on the generic DCF model LEV.

Table 4.20: The DCF model results for VCM6 research trial treatments, including the total treatment cost and a description of the tested treatments.

Treatment	Treatment details	Treatment cost (Rands)	Rot.Vol (tons ha^{-1})	LEV (R ha^{-1})	NPV (R ha^{-1})	EAI (R ha^{-1})	IRR (%)	BCR
T1	4 m + 8m; Manual removal secondary coppice regrowth at 0.75 m [Control]	2 001	221	**121 122**	**37 472**	**2 174**	**19**	**1.65**
T3	4 m + 8m; secondary coppice regrowth sprayed with glyphosate at 0.6% when 0.75 m high	1 866	221	**121 431**	**37 580**	**2 181**	**19**	**1.66**
T5	4 m + 8 m; Broadcast application of fertiliser 321 kg ha^{-1} NPK(4:1:1); manual removal of secondary regrowth at 0.75 m high	4 054	221	**115 535**	**35 525**	**2 061**	**18**	**1.62**
T6	4 m + 8 m; Chemical control with glyphosate 4 l/ha; manual removal of secondary coppice regrowth when 0.75 m high	3 800	221	**116 313**	**35 796**	**2 077**	**18**	**1.63**

Results marked in orange are below the LEV of the control treatment, while those in green are above the control treatment LEV.

4.5.2.7. DCF model results for VCM7 trial

The LEV ranged from R42 203 to R44 032, and the treatments IRR of 10% was the same for all treatments. Although, there were significant differences reported in the number of operations carried out to reduce coppice growth. Using the treatment mean Rot.Vol from FES indicated that the cheaper treatment 7 to be more profitable. Further results are presented by Table 4.21.

All the treatments had higher LEVs than the generic DCF model LEV and the land value. Thus, the investment project was acceptable for all treatments. Therefore, the re-establishment with coppice could be seen to be more profitable than re-establishment with planting based on the generic DCF model LEV.

Table 4.21: The DCF model results for VCM7 research trial treatments, including the total treatment cost and a description of the tested treatments

Treatment	Treatment details	Treatment cost (Rands)	Rot.Vol (tons ha^{-1})	LEV (R ha^{-1})	NPV (R ha^{-1})	EAI (R ha^{-1})	IRR (%)	BCR
T1	No burn + Manual bashing [Control]	1 000	155	**42 789**	**12 114**	**703**	**10**	**1.43**
T2	Burn + Manual bashing	1221	155	**42 244**	**11 888**	**690**	**10**	**1.43**
T3	Metsulfuron-methyl + water + 600 g kg^{-1} + 80 g/100 l + Actipron + Foliar spray	1 257	155	**42 203**	**11 871**	**689**	**10**	**1.43**
T4	Triclopyr (butoxy ethyl ester) + water + 480 g/kg + 750 ml/100 l + Actipron + Foliar spray	723	155	**43 422**	**12 377**	**718**	**10**	**1.44**
T5	Glyphosate trimesium + water + 720 g l^{-1} + 3.33 l/100 l + Add 2 + cut surface spray	896	155	**43 028**	**12 213**	**709**	**10**	**1.44**
T6	Triclopyr (amine salt) + water + 360 g l^{-1} + 3 l/100l + Actipron super + cut surface spray	500	155	**43 933**	**12 589**	**730**	**10**	**1.44**
T7	Triclopyr (amine salt) + water + 360 g l^{-1} + 3 l/100l + Actipron super + cut surface spray	457	155	**44 032**	**12 630**	**733**	**10**	**1.44**

Results marked in orange are below the LEV of the control treatment, while those in green are above the control treatment LEV.

4.5.2.8. DCF model results for VCM8 trial

The LEV ranged from R32 979 to R35 500, and the treatments IRR of 8% was the same for all treatments. Even though, there were no significant differences reported in Rot.Vol between treatments tested. Using the treatment mean Rot.Vol from FES indicated that the cheaper treatment (T2) to be more profitable. Further results described by Table 4.22.

All the treatments had higher LEVs than the generic DCF model LEV and the land value. Thus, the investment project was acceptable for all treatments.

Table 4.22: The DCF model results for VCM8 research trial treatments, including the total treatment cost and a description of the tested treatments.

Treatment	Treatment details	Treatment cost (Rands)	Rot.Vol (tons ha^{-1})	LEV (R ha^{-1})	NPV (R ha^{-1})	EAI (R ha^{-1})	IRR (%)	BCR
T1	Weed free control; Manual [Control} Fertiliser applied at planting	1 628	155	33 330	8 193	475	8	1.37
T2	Weedy Fertiliser applied at planting	627	155	35 500	9 092	528	8	1.39
T3	Cowpeas + Single row planted at 1.5 m from tree row + intra-row spacing of 0.15 m + density of 7 333 plants/ha; fertiliser at 10 g NPK (40)(2:3:2) m^{-1} Fertiliser applied at planting	1 724	155	32 992	8 053	467	8	1.37
T4	Cowpeas + Double row planted 1 m apart + 1 m from the tree row with the same intra-row espacement + density of 15 666 plants/ha; fertiliser at 10 g NPK (40)(2:3:2) m^{-1} Fertiliser applied at planting	1 730	155	32 978	8 047	467	8	1.37

Results marked in orange are below the LEV of the control treatment, while those in green are above the control treatment LEV.

4.5.2.9. DCF model results for VCM9 trial

The LEV ranged from R31 445 to R35 500, and the treatments IRR of 8% was the same for all treatments. Although, there were no significant differences in Rot.Vol between treatments tested. Using the treatment mean Rot.Vol from FES indicated that the cheaper treatment 1 (control) to be more profitable. Further results are illustrated by Table 4.23.

All the treatments had higher LEVs than the generic DCF model LEV and the land value. Thus, the investment project was acceptable for all treatments.

Table 4.23: The DCF model results for VCM9 research trial treatments, including the total treatment cost and a description of the tested treatments.

Treatment	Treatment details	Treatment cost (Rands)	Rot.Vol (ton ha^{-1})	LEV (Rands)	NPV (Rands)	EAI (Rands)	IRR (%)	BCR
T1	Weedy control [Control] Fertiliser applied at planting	627	155	**35 500**	**9 092**	**528**	**8**	**1.39**
T2	Cowpeas planted in a single row;1.5 m from tree rows; fertiliser Fertiliser applied at planting	1724	155	**32 992**	**8 053**	**467**	**8**	**1.37**
T3	Cowpeas planted in a double row ;1 m from tree rows; fertiliser Fertiliser applied at planting	1 730	155	**32 978**	**8 047**	**467**	**8**	**1.37**
T4	Cowpeas planted in a single row ;1.5 m from tree rows + spray metolachlor + Paraquate (2.5 + 2.0 l ha^{-1} product) stiker (0.5 l ha^{-1}); fertiliser Fertiliser applied at planting	2 395	155	**31 459**	**7 417**	**430**	**8**	**1.36**
T5	Cowpeas planted in a double row, 1 m from tree rows + spray metolachlor + Paraquate (2.5 + 2.0 l ha^{-1} product) and sticker (0.5 lha^{-1}); fertiliser Fertiliser applied at planting	2 401	155	**31 445**	**7 411**	**430**	**8**	**1.36**
T6	Weed free Fertiliser applied at planting	1 628	155	**33 330**	**8 193**	**475**	**8**	**1.37**

Results marked in orange are below the LEV of the control treatment.

4.5.2.10. DCF model results for VCM11 trial

The LEV ranged from R127 260 to R141 490, and the treatments IRR were insignificant ranging from 16 to 17%. Furthermore, the application of T2 costs R3 001 more than the control treatment, but T2 increased rotation volume by 29% and increased LEV by R26 485. Similarly, the IRR increased from 12% to 15% indicating T2 as the most profitable treatment. Further results are described by Table 4.24.

All the treatments had higher LEVs than the generic DCF model LEV and the land value. Thus, the investment project was acceptable for all treatments. Therefore, the re-establishment with coppice could be seen to be more profitable than re-establishment with planting based on the generic DCF model LEV.

Table 4.24: The DCF model results for VCM11 research trial treatments, including the total treatment cost and a description of the tested treatments.

Treatment	Treatment details	Treatment cost (Rands)	Rot.Vol (tons ha^{-1})	LEV (R ha^{-1})	NPV (R ha^{-1})	EAI (R ha^{-1})	IRR (%)	BCR
T1	Reduced to 2 stems per stool [Control]	2 334	339	**127 260**	**50 603**	**2 936**	**16**	**1.74**
T2	Reduced to 1 stem per stool	2 334	342	**128 594**	**51 197**	**2 971**	**17**	**1.74**
T3	Shoot below predetermined minimum DBH were removed	2 334	366	**141 490**	**56 937**	**3 304**	**17**	**1.77**

Results marked in green are above the LEV of the control treatment.

4.5.3. Sensitivity Analyses Results for VCM Research Trials

Sensitivity analyses results indicate that when an optimistic (3.5 and 4.5%) real discounted rate is used the land expectation value (LEV) increases. Conversely, at a pessimistic (6.5 and 7.5%) real discounted rates the LEV decreases.

4.5.4. Overview of financial analyses results for VCM research trials

Vegetation and coppice management (VCM) research trials focusing on vegetation management (VCM1, VCM2, VCM3, VCM4, VCM8 and VCM9) were located in the Zululand coastal plain region. The research trials were established under *E. grandis x camaldulensis* species, excluding RM2 which was established with *E. grandis x urophylla*. Different vegetation management techniques tested in the research trials included:

- A weedy control treatment.
- Manual vegetation control, this includes row-weeding, ring-weeding and inter-row weeding.
- Chemical vegetation control, this includes a combination of different herbicides approaches (e.g. glyphosate and metolachlor).
- Cultural vegetation control, a cover crop which includes either cowpea planted either on a single or double row with fertiliser.
- Burning of slash.

Vegetation management was carried out during the re-establishment period (between planting and canopy closure), considered the most important phase for weed control

(Little and Rolando, 2012). Because negative impacts to tree performance during this period are likely to be carried through to clear-felling (Little and Rolando, 2012). However, for VCM2 vegetation control was carried out throughout the trial.

Little and Rolando (2012) pointed out benefits derived from vegetation management, which includes increasing stand uniformity, reducing canopy closure time, a reduction in seedling mortality, increasing yields and reducing rotation periods. For this study, financial returns from vegetation management trials were determined from the increase in yields and the costs of application.

There was no control treatment for VCM2 research trial and all the tested treatments were carried out with a manual vegetation control technique. Furthermore, investments made to increase the number of year's treatments were kept weed-free could not be justified. Considering that, there were no significant differences in rotation volume (Rot.Vol) for tested treatments. Thus, financial returns declined with an increase in the number of years where treatments are kept weed-free. For example, land expectation value (LEV) decreased by 25%, while weeding costs increased by over 70% (see Table 4.16) due to an increase in the number of years weed control was carried out.

Vegetation management control techniques for research trials (VCM1, VCM3 and VCM4) were successful in increasing yield (volume) at rotation age. Considering that, there were significant differences in Rot.Vol of the tested treatments in the mentioned VCM trials. On the other hand, VCM8 and VCM9 had no significant difference in Rot.Vol of the tested treatments. Thus, the control treatments had higher financial returns, this is further presented in Figure 4.7, which describes the LEVs for all the vegetation management techniques tested per VCM trial.

Cover-crop with cowpeas weed control technique was imposed in all the VCM trials presented in Figure 4.7, excluding VCM3. Planted either in a single or a double row, in combination with manual or chemical weed control. For VCM1, cowpeas established in a single row with a combination of chemical weed control had the second highest returns on investment. Yet, for VCM4 cover-crop weed control technique had the least financial returns, but the LEV (R50 826 ha^{-1}) was 21% more than control treatment. Investments made toward the use of cover crop as a weed control technique are justified financially due to an increase in yield and a reduction in weed control costs compared to other techniques. However, financial gains are lower compared to other weed control techniques (e.g. manual and chemical weed control).

Manual vegetation control for VCM1 had the highest financial returns (LEV of R83 6675 ha^{-1}), LEV was 31% higher than control treatment. Although it had the highest treatments costs, the increase in yield was able to justify the initial investment. Similarly, manual vegetation control had the highest returns (R93 227 ha^{-1}) for VCM4, were LEV was 56% higher than control treatment. Furthermore, manual weed control had the highest treatment costs for both trials, however, the increase in yield was able to justify the initial investments. Thus, there were sound financial gains in intensive manual weed control technique for the mentioned research trials, as illustrated in Figure 4.7.

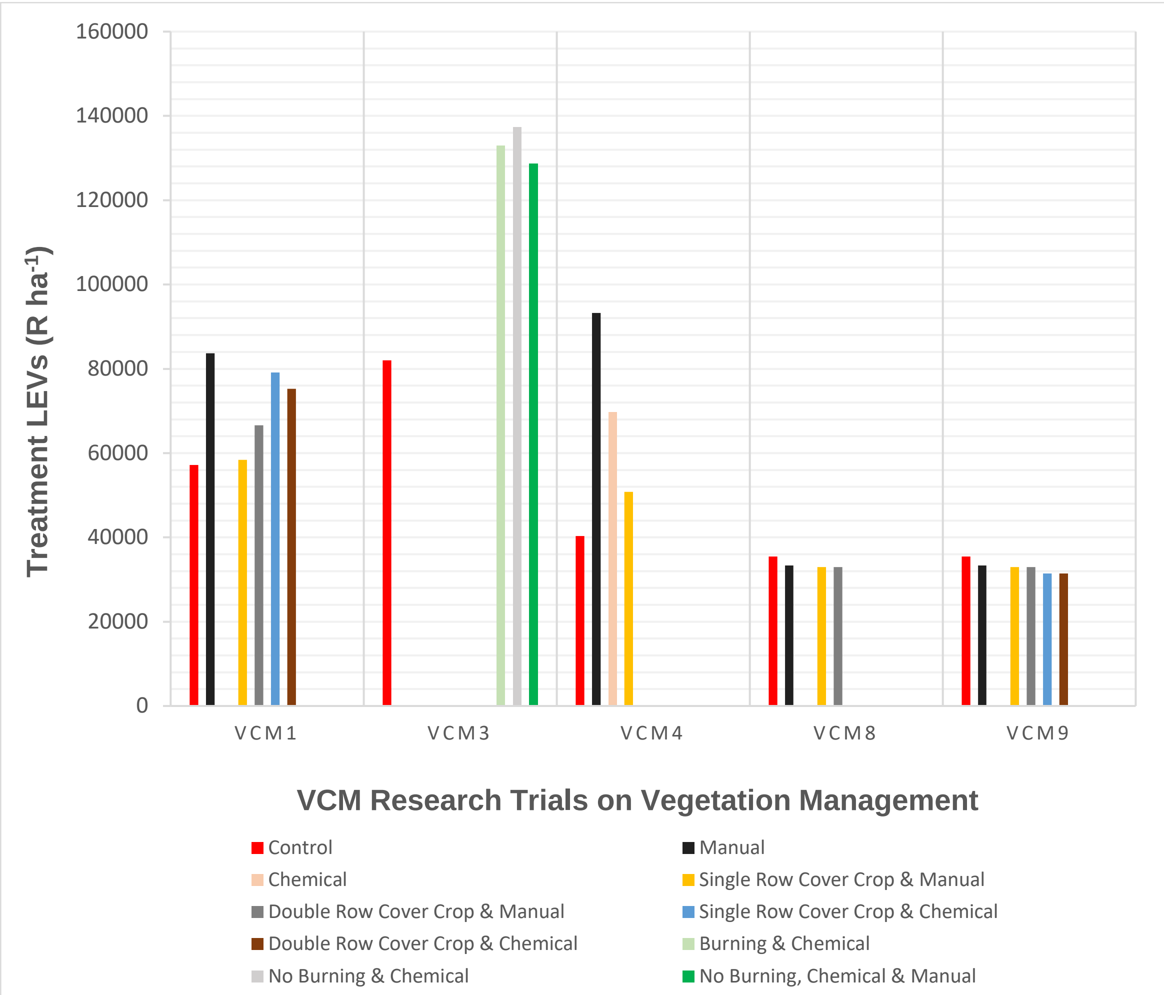


Figure 4.7: Treatment LEVs for VCM research trials focusing on vegetation management. Further, compares the LEVs for different vegetation management techniques.

The following research field included coppice management trials, where stands have been re-established through coppice reduction. According to Viero and du Toit (2012), it is common practice in *Eucalyptus* plantations to allow regeneration from coppice shoots for one or two rotations after clear-felling. Furthermore, coppice management research trials (VCM5, VCM6, VCM7 and VCM11) evaluated in this study, focused on cost-effective techniques for coppice management. In addition, VCM6 research trials further investigated the effect of fertilisation during the period of coppicing.

There were no significant differences reported in Rot.Vol for the tested treatments in the above-mentioned research trials. Considering that, only the mean volume was reported for some of the treatments. Thus, financial analyses results indicated that high financial returns would be attained from treatments with the lowest costs.

Additional investments carried out for manual and chemical weed control for VCM5 did not result in financial returns. Therefore, the additional investment to incorporate weed control in re-establishment with coppice, reduced financial gains as there was no increase in yield to sustain the rise in treatment costs (see Table 4.19). Likewise, the additional application of fertiliser (treatment 5) for VCM6 research trial could not be justified. Resulting in reduced financial gains pertaining to an increase in re-establishment costs.

4.6. FOREST MANAGEMENT: *EUCALYPTUS* REGENERATION

4.6.1. Meta-Analyses Results for ER Research Trials

These results are based on eight research trials, a full description of the results is given in Appendix D.

Research trials investigated the effect of soil-amended hydrogel and water planting on tree survival rates and ground line diameter (gld). However, ER2 was a pot trial investigating the influence of *Eucalyptus* growth and root development. ER3 treatment factors investigated into the interaction of *E. grandis* micro-cutting and seedlings with weeding as a split treatment factor.

Tree survival rates were calculated at different days after planting (dap) for each research trial. *Eucalyptus* regeneration one (ER1) trial had 25 treatments tested, these included five water levels (0 ml, 250 ml, 500 ml, 1 000 ml and 5 000 ml) and five hydrogels levels (0 g, 3 g, 6 g, 9 g and 12 g). However, the tree survival rates of six treatments were reported including the control treatment (zero application of water and hydrogel). For ER4 only four of 25 treatment tree survival rates were reported, ER4 also had five water levels (0 ml, 500 ml, 1 000 ml, 2 000 ml, and 4 000 ml) and five hydrogel levels (0 g, 3 g, 6 g, 9 and 12 g).

Furthermore, survival difference (SD) were calculated for the ER research trials to determination the percentage improvement of tested treatments survival rates at different dap, relative to the control treatment (dry planting). The highest, lowest and average survival differences are illustrated in Figure 4.8.

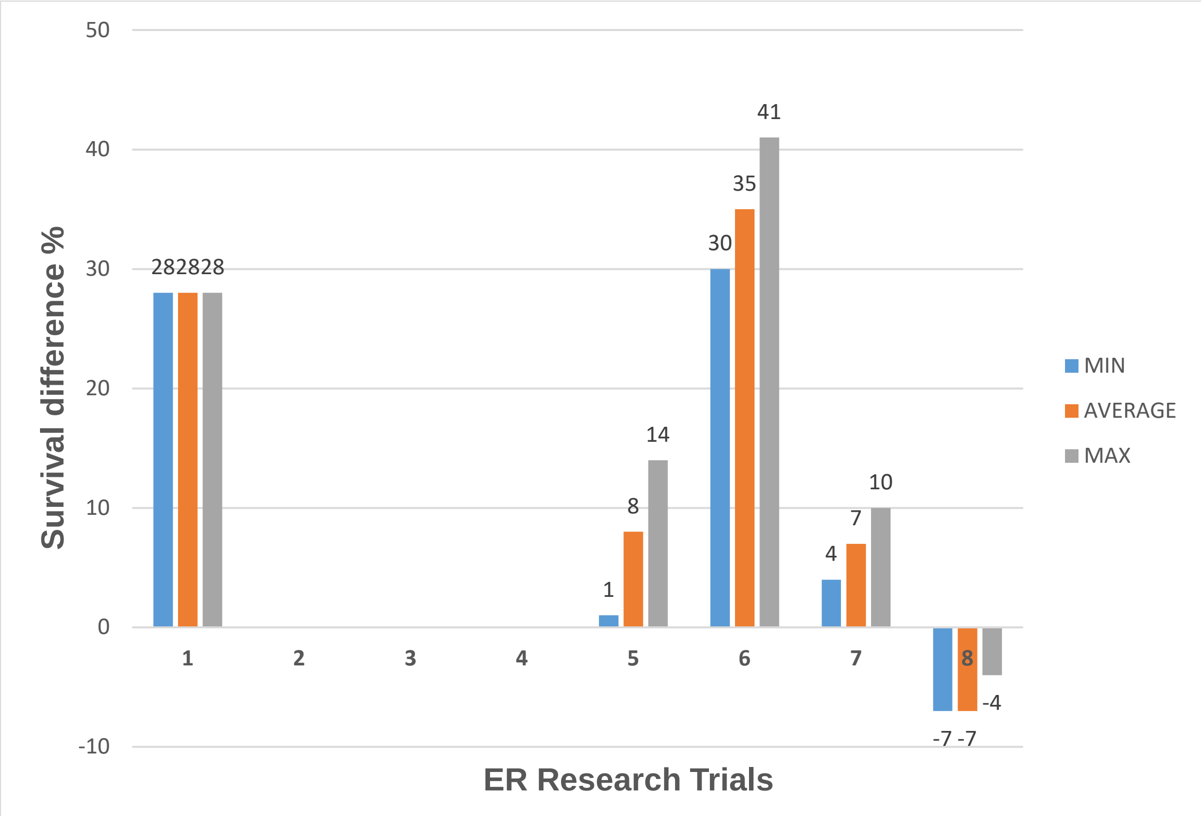


Figure 4.8: The lowest, average and highest treatment survival difference (%) improvements relative to the control treatment for ER research trials.

Tested treatments for ER1 had the same SD mainly because of the same tree-survival rates. For ER5 the maximum SD was 14% and a minimum of 1%, indicating the application of water improved tree survival better than hydrogel application. All the trials had a positive survival difference, except ER8 where the tested treatments had negative SD's. Reason being, the control treatment performed better than the hydrogel and water treatment factors.

4.6.2. Cost Comparison Results for ER Research Trials

Results from the cost comparison provide a financial perspective on the relationship between planting and blanking costs relative to tree survival rates. Although, the cost analyses study omitted ER2 and ER3 due to insufficient information (tree survival rates not reported). Furthermore, the comparison results are presented as follows per *Eucalyptus* regeneration research trial:

4.6.2.1. Results for ER1 research trial

The following trial results demonstrate treatment 2 as the optimum treatment, further illustrated by Table 4.25. Furthermore, the control treatments (dry planting) had the lowest tree survival rate of 71% and the least expensive planting costs and a survival difference (SD) of 28%. Treatment 2 had the lowest total cost (planting and blanking costs) of R2 637 and had a survival rate of 90%. Although the control treatment had the lowest planting cost initially, it had the higher blanking costs due to a low survival rate %.

Table 4.25: Cost summary between planting and blanking costs for tested treatments for ER1 (tree survival rates (%) at 80 days after planting).

Treatment	Treatment details	Tree survival (%)	Cost (R ha^{-1})		Total cost (R ha^{-1})	% of total cost	
			Planting cost	Blanking cost		Planting	Blanking
T1	0 ml of water + 0 g of hydrogel [Control]	71%	1 948	765	2 714	71.8%	28.2%
T2	500 ml of water + 3 g of hydrogel Applied during summer	90%	2 188	449	2 637	83%	17%
T3	500 ml of water + 12 g of hydrogel Applied during summer	90%	2 907	449	3 356	86.6%	13.4%
T4	1 000 ml of water + 9 g of hydrogel Applied during summer	90%	2 668	449	3 117	85.6%	14.4%
T5	5 000 ml of water + 3 g of hydrogel Applied during summer	90%	2 189	449	2 637	83%	17%
T6	5 000 ml of water + 12 g of hydrogel	90%	2 908	449	3 357	86.6%	13.4%

Treatment	Treatment details	Tree survival (%)	Cost (R ha^{-1})		Total cost (R ha^{-1})	% of total cost	
			Planting cost	Blanking cost		Planting	Blanking
	Applied during summer						

4.6.2.2. Results for ER4 research trial

The following results demonstrate treatment 3 as the optimum treatment, further illustrated by Table 4.26. The control treatment tree survival rate was not reported, however, the water treatment (T1) had a tree-survival rate of 63%. Furthermore, treatment 3 and T4 had the same tree survival rates but T4 had a higher total cost of R2 981.

Both treatment 3 and 4 had a 100% survival rate but T3 had the lowest planting cost as less water and hydrogel had been applied at planting. Treatment 1 and 2 had a higher total cost compared to treatment 3, this was due to a lower tree survival rate. Furthermore, these results indicate that an increase in planting costs increased the tree survival rate until a tree survival rate of 100% was reached (T3). However, a further increase in planting cost (T4) would not have an effect on the survival rate

Table 4.26: Cost summary between planting and blanking costs for tested treatments for ER4 (tree survival rates (%) at 118 days after planting).

Treatment	Treatment details	Tree survival (%)	Cost (R ha^{-1})		Total cost (R ha^{-1})	% of total cost	
			Planting cost	Blanking cost		Planting	Blanking
T1	4 000 ml of water Applied during winter	63%	1 782	1 032	2 814	63%	37%
T2	500 ml of water + 3 g of hydrogel Applied during winter	73%	2 082	777	2 858	73%	27%
T3	1 000 ml water + 6 g hydrogel Applied during winter	100%	2 381	0	2 381	100%	0%
T4	2 000 ml of water + 12 g hydrogel Applied during winter	100%	2 981	0	2 981	100%	0%

4.6.2.3. *Results for ER5 research trial*

The following results demonstrate treatment 3 as the optimum treatment, further illustrated by Table 4.27. The control treatment tree survival rate was 73% and had the highest blanking costs. Water treatments (T2 and T3) performed better than the hydrogel treatment (T4). Furthermore, T3 had a SD of 14% and was least expensive.

These results indicate that the use of hydrogel during planting in winter did increase the tree survival rate compared to water planting and thus, it justify increased the planting costs.

Table 4.27: Cost summary between planting and blanking costs for tested treatments for ER5 (tree survival rates (%) at 316 days after planting).

Treatment	Treatment details	Tree survival (%)	Cost (R ha^{-1})		Total cost (R ha^{-1})	% of total cost	
			Planting cost	Blanking cost		Planting	Blanking
T1	0 ml water [Control]	73%	2 365	844	3 209	73.7%	26.3%
T2	1 000 ml water Applied during winter	83%	2 365	636	3 001	78.8%	21.2%
T3	2 000 ml water Applied during winter	83%	2 365	636	3 001	78.8%	21.2%
T4	1 000 ml water + 3 g hydrogel Applied during winter	74%	2 665	824	3 488	76.4%	23.6%

4.6.2.4. *Results for ER6 research trial*

The following results demonstrate treatment 2 as the optimum treatment, further illustrated by Table 4.28. The control treatment tree survival rate was 71% and thus had the highest blanking costs. Water treatment (T2) performed below the hydrogel treatment and had higher total costs. Furthermore, T3 had a SD of 41% and was least expensive.

These results indicate that the use of water and hydrogel planting during summer increased the survival rate and reduced the blanking costs. Although these treatments had higher planting costs, due to a lower tree survival rate of the control treatment, the total costs for the tested treatments were lower than the control treatment.

Table 4.28: Cost summary between planting and blanking costs for tested treatments ER6 (tree survival rates (%) at 91 days after planting).

Treatment	Treatment details	Tree survival (%)	Cost (R ha^{-1})		Total cost (R ha^{-1})	% of total cost	
			Planting cost	Blanking cost		Planting	Blanking
T1	0 ml water [Control] Applied during summer	71%	1 948	765	2 7134	71.8%	28.2%
T2	1 000 ml water Applied during summer	92%	1 949	416	2 364	82.4%	17.6%
T3	1 000 ml water + 3 g hydrogel Applied during summer	100%	2 188	0	2 188	100%	0%

4.6.2.5. Results for ER7 research trial

The following results demonstrate treatment 3 as the optimum treatment, further illustrated by Table 4.29. The control treatment tree survival rate was 91% and thus had the highest blanking costs. Water treatment (T2) performed below the hydrogel treatment and had higher total costs. Furthermore, T3 had a SD of 10% and was least expensive.

These results indicate that both water and hydrogel planting increased the tree survival rate when applied during spring in this site. Although, the control treatment had a tree survival rate above 90% the blanking costs increased the total costs and thus, had a higher total cost compared to the two tested treatments.

Table 4.29: Cost summary between planting and blanking costs for tested treatments for ER7 (tree survival rates (%) at 182 days after planting).

Treatment	Treatment details	Tree survival (%)	Cost (R ha^{-1})		Total cost (R ha^{-1})	% of total cost	
			Planting cost	Blanking cost		Planting	Blanking
T1	0 ml water [Control]	91%	2 365	470	2 834	83.4%	16.6%
T2	1 000 ml water Applied during spring	95%	2 365	386	2 751	86%	14%
T3	1 000 ml water + 3 g hydrogel Applied during spring	100%	2 665	0.0	2 665	100%	0%

4.6.2.6. Results for ER8 research trial

The following results demonstrate the control treatment (T1) as the optimum treatment, further illustrated by Table 4.30. The water treatment (T2) performed better than the hydrogel treatment, had a higher tree survival rate and lowest total costs.

These results indicated that the application of water and hydrogel during planting in winter did not increase the tree survival rate and reduced the total establishment costs. Therefore, the application of water and hydrogel did not guarantee an increase in tree survival rate, but increased planting costs.

Table 4.30: Cost summary between planting and blanking costs for tested treatments for ER8 (tree survival rates (%) at 244 days after planting).

Treatment	Treatment details	Tree survival (%)	Cost (R ha^{-1})		Total cost (R ha^{-1})	% of total cost	
			Planting cost	Blanking cost		Planting	Blanking
T1	0 ml water [Control]	90%	2 365	490	2 855	82.8%	17.2%
T2	1 000 ml water Applied during winter	86%	2 365	574	2 939	80.5%	19.5%
T3	1 000 ml water + 3 g hydrogel Applied during winter	84%	2 665	615	3 280	81.2%	18.8%

4.6.3. Overview of cost comparison analyses results for ER research trials

All the tested water and hydrogel treatments had significant differences reported in tree-survival rates for all the ER research trials. Tree-survival rates for both water and hydrogel treatments were not consistent. For instance, the application of 0.5 l of water and 3 g of hydrogel (treatment 2) for ER1 had a tree-survival rate of 90%. While the same treatment applied in ER4 research had a tree-survival rate of 73%. Similarly, other ER research trials had different tree-survival rates while the same treatment of water and hydrogel was applied.

According to Viero and Button (2007) ER6, ER7 and ER8 were re-established on high, medium and low risk respectively. These are based on planting seasonal observations, ER6 (high risk) planted during summer (hot days and dry spells), ER7 (medium risk) planted during spring (warm to hot days with spring rain) and ER8 (low risk) planted during winter (cool days and nights associated with heavy due) (Viero and Button, 2007). These site conditions could be the reasons why, the survival difference (SD) improvements were higher on high-risk site, intermediate on medium risk site and negative on low-risk site (see Figure 4.8, illustrating SD improvements).

Furthermore, application of water and hydrogel for ER6 and ER7 were cost-effective, they increased the tree-survival rates and further reducing total cost for re-establishment (see Table 4.28 and 4.29). While the application of water and hydrogel for ER8 which was established on a low-risk site was not cost-effective. Therefore, the control treatment (dry) was cost-effective, resulting in higher tree-survival rates and lower re-establishment costs. However, these differences cannot be attributed only to the observed site conditions

Financial returns (gains) associated with the application of soil-amended hydrogel are justified with a significant increase in tree-survival rates leading to a reduction in blanking costs. However, because sites conditions and quality differ, and planting is at times carried out at different seasons to minimize the total unplanted area (TUP). Returns on investments for hydrogel should take these mentioned factors into consideration, as hydrogels prices increase re-establishment costs significantly.

5. CHAPTER FIVE

DISCUSSION

5.1. INTRODUCTION

The site productivity of a plantation is generally affected by climate (temperature and rainfall), topography and soil type (the depth and fertility of the soil) (Rietz *et al*., 2006). Harrison *et al*. (2005) highlighted the need for site specific financial analyses information for various species tested in smallholder plantations. Such information could assist growers in deciding on the most financially profitable species for their site. The previous chapter further indicated than an increase in intensive forest management does not automatically guarantee an increase in volume at rotation age. South *et al*. (2010) mentioned that increasing of inputs would typically results in an increase in volume, although there are some exceptions. For instance, for on-site fertiliser recommendation trials, mid-rotation fertiliser trials did not results in an increase in volume production. Furthermore, the application of fertiliser and weed control in coppice managed stand also did not increase volume production, however, only resulted in an increase in input costs.

This chapter discusses the reporting of research results for financial analyses and how these can be a limiting factor in evaluating financial returns of research trials. Further discusses financial returns evaluated with the use of a discounted cash flow (DCF) model and how these differ based on site productivity. Lastly, it discusses the results of the cost comparison study and the factors affecting tree survival rates with the application of water and/or hydrogel.

5.2. REPORTING OF RESEARCH RESULTS FOR FINANCIAL ANALYSES

One of the outcomes of this study is to “provide a better understanding of reporting on research results”. Therefore, this section considers the challenges encountered in accurately evaluating financial returns (gains) from reported research results using the generic DCF model.

Experimental trials are generally used to investigate or quantify a factor(s) in question, while other factors are kept constant. Based on the meta-analyses carried out, it is clear that there was no straight forward standard in reporting research results carried out through research trials. Although, this was not the case with on-site specific fertiliser recommendations (FR) research trials.

All ten FR research trials results reported, could be used for financial analysis mainly because of: (i) tested treatments can be quantified financially, (ii) rotation volume for all the treatments were reported and (iii) the research results were reported until rotation age (end of trial).

Certain vegetation and coppice management (VCM) research trial treatments, however, had no significant difference in rotation volume and as a result, volumes were not documented. Although, at times when there is no significant difference reported in rotation volume, mean volumes were reported. Therefore, rotation volume is projected (assumed), in this particular study projected with the generic DCF model. In addition, the duration of the research trials (rotation age) were not reported.

Similarly, for the eucalypt regeneration (ER) research trials, which lasted between 40 and 428 days, no rotation volume information was reported. Considering that, the main treatment factor (application of hydrogel), as mentioned by Viero and du Toit (2012) if correctly applied would ensure optimal tree survival and early growth under specific conditions. Crous (2016) further pointed out that, the application of hydrogel doesn’t only have an effect on tree survival rates but can have an effect on tree growth.

5.3. ON-SITE SPECIFIC FERTILISER RECOMMENDATIONS

Literature on the economic results based on the application of fertilisation is rare, in comparison to the literature on biological and environmental results of fertilisation (Ghebremichael *et al*., 2005; Hedwall *et al*., 2014).

The kind of effect the application of fertiliser in plantation forestry has on financial results is determined by the change in volume (m^3) at harvesting and the cost(s) of fertiliser at the year of application compounded to rotation age. Hedwall *et al*. (2014) put forward a view that financial analyses results are highly depended on the effect of fertiliser on volume growth. Considering, the primary reason for fertiliser application is to increase the productivity of the site by increasing soil fertility, which in turn increases wood yield on the exact site (Ghebremichael *et al*., 2005; Titshall, 2013). On the other hand, Ondro and Constatino (1990) mentioned how the application of fertiliser can reduce the rotation period by obtaining the same yields.

According to du Toit *et al*. (2010), in short rotation plantations the period from clear-felling to canopy closure is an important stage of opportunity for a sustainable increase in productivity. This could further explain a reduction in financial gains from mid-rotation fertilisation, which is outside the period of increasing and sustaining productivity. Conversely, research trials fertilised prior to canopy closure had higher financial returns, which falls in the period of increasing productivity.

5.4. FOREST MANAGEMENT: RESIDUE MANAGEMENT

A review study on South Africa research conducted by du Toit *et al*. (2010) put forward a view that, research trials conducted on intensive site preparation techniques have not resulted in significant growth improvements across a range of sites established under *Eucalyptus* stands. In this study, residue management (RM) research trials evaluated, were initiated to investigate potential reduction in site productivity over successive rotations.

Harvesting and residue management trials indicated a decline in financial returns through successive rotations. For this particular reason, it could be argued that a decline in site productivity was due to soil compaction caused by harvesting and reside management techniques. Since du Toit *et al*. (2010) mentioned that long term site productivity changes may result due to soil compaction and residue management caused by harvesting and extraction of timber during clear-felling operations. However, Smith and du Toit (2005) found the effect of soil compaction on tree growth to be insignificant. According to Rietz *et al* (2006), soil compaction and harvesting residue management techniques are regarded as potential threats to plantation site productivity in the long run. Rietz and Little (2014) further pointed out soil organic carbon and nutrients as the major contributing factors to a decline in site productivity. Which is further escalated by the burning of harvest reside and an increase in the severity and occurrence of pest and diseases (Rietz and Little, 2014).

5.5. FOREST MANAGEMENT: VEGETATION AND COPPICE MANAGEMENT

According to du Toit *et al*. (2010), "*the presence of vegetation during the establishment of Eucalyptus plantations may result in sub-optimal tree growth through competition for light, water, nutrient and growing space*". In this regard, vegetation management is one of the most important factors which improve tree growth in young plantations (Little and Rolando, 2012). Although, vegetation management techniques are a major cost contributor to silvicultural costs, final volume at rotation age should be considered to determine the most profitable technique (Little and van Staden, 2005).

The results of this study indicated an increase yield and financial returns due to different vegetation management techniques. Likewise, Little *et al*. (2002) and, Little and van Staden (2003) pointed out a number of benefits from vegetation management, including an increased yield and a reduced canopy closure time and reduced rotation periods.

Manual vegetation management technique had higher financial returns from the research trials in comparison to other vegetation management options. Thus, the additional investment made to these techniques was justified. Considering that Little *et al*. (2002) mentioned that vegetation management techniques with a positive economic value should be considered as a viable management option. However, for a vegetation management technique to be economically viable it should be cheaper than other treatments and if it is more expensive the financial returns should justify the additional investment (Little *et al*., 2002; Little and van Staden 2005). This was evident, as at times the manual vegetation management technique was more expensive than other treatments but the financial returns (based on LEV) justified the additional costs and were higher than other tested treatments. These results support a view put across by du Toit *et al* (2010) that vegetation management research trials have shown commercial applicability.

Re-establishment with coppice indicated a decline in financial returns with the application of weed control. This was because the additional costs could not be justified as there was no significant increase in yields (reported) at rotation age. Similarly, Little (2007) found that weed control from coppice managed stands indicated no returns. Little and du Toit (2003) also found that weed control and the application of fertiliser to be non-beneficial in such stands. Additionally, Viero and du Toit (2012) have mentioned that coppice managed stands do not respond to the application of fertiliser after coppicing. Furthermore, this study demonstrated lower financial returns for the application of fertiliser in coppice managed stands, higher treatment costs could not be justified.

5.6. *EUCALYPTUS* REGENERATION RESEARCH

In the Zululand region, the planting season is considered to be limited and establishment costs are high (Viero *et al*., 2000). Thus, the use of water and soil-amended hydrogel is generally used to increase the planting period. For instance, Viero *et al*. (2002) initiated a research trial with an objective to extend the planting period into the winter season. They found that, there is a possibility to significantly extend the planting window and reducing the application of water at planting.

However, this study did not consider whether the additional treatment costs would be justified by an increase in yield at rotation or by an increase in tree survival rate. Considering that, Viero *et al*. (2002) further found a significant increase in tree performance (based on a corrected biomass index) due to the application of soil-amended hydrogel. Similarly, based on a series of water and hydrogel planting research trials, Viero *et al*. (2008) found water and hydrogel planting to have a significant effect on better initial tree growth and uniformity. Although, Viero and Button (2007) found that planting with soil-amended hydrogel rather than water would result in insignificantly better tree survival and growth. The cost comparison study indicated that the treatment costs for planting with hydrogel to be higher than water planting and at certain instance (ER8 winter planting) have a lower tree survival rate as opposed to water and dry planting.

According to Viero and du Toit (2012), the application of soil-amended hydrogel ensures optimal tree survival and early growth under specific conditions, provided its application is carried out correctly. Crous (2016) further argued that hydrogel does not only have an effect on tree survival rates but also has an effect on tree growth. *Eucalyptus* regeneration (ER) research trial results discussed in this section, only accounted for tree-survival rates due to the application of water and hydrogel in the coastal Zululand region. Thus, the effect water and hydrogel application have on incremental growth at rotation could not be simulated financially.

Considering that regeneration trials were established on sandy loamy sandy soil textures. The inconsistency in tree-survival rates for hydrogel application can be due to the differences in soils properties and specific conditions such as the type of species planted (Crous, 2016). On better quality site the potential returns to investment associated with hydrogel application are considered to be higher than poor quality sites (Crous, 2016).

6. CHAPTER SIX

CONCLUSION AND RECOMMENDATIONS

6.1. CONCLUSION

The aim of this study was to provide a better understanding of the reporting of research results, provide estimated financial gains in implementing of research results and illustrate the challenges of financially evaluating returns of forestry research based on reported research trial information.

This study developed a generic discounted cash flow (DCF) model for estimating financial returns from research results from four research fields: (i) on site-specific fertiliser recommendations (FR), (ii) forest management focusing on residue management (RM), (iii) vegetation and coppice management (VCM) research, and (iv) *Eucalyptus* regeneration (ER) research.

The findings of the study demonstrated that in order to predict (or estimate) financial returns (gains) of research results based on experimental trials. Reported research trial findings have to have sufficient information for financial analyses to be carried out with DCF models. This was evident with the ER research field were financial analyses could not be conducted, due to limited information on reported research results.

However, a cost analyses approach was adopted for ER research trials and the finding indicated that benefits from the application of water and soil-amended hydrogel at planting should not only consider the increase in tree-survival rates and costs reductions. The returns should consider site conditions, planting times and site productivity to justify the added investment.

Estimated financial returns for FR research trials were around R75 601 ha^{-1} and 9% higher than control treatment on a poor fertility site, based on the land expectation value (LEV) and internal rate of return (IRR) respectively. On low fertility site LEV and IRR were R28 006 ha^{-1} and 1% higher, R29 641 ha^{-1} and 2% on medium fertility site, R38 869 ha^{-1} and 2% higher than control treatment on high fertility sites. However, there were no financial gains for FR mid rotation research trials compared to the control treatment. Furthermore, added investment returns were between R1 232 and

R34 346 ha^{-1} lower than control LEVs and 0 to 9% lower than control IRRs. Thus, investments made towards intensive forest management, in this regard the application of fertiliser at mid rotation age do not guarantee financial gains.

Estimated financial gains for RM research trial indicated that soil compaction and residue management techniques can have a negative effect on returns of upcoming rotations. Findings from the study found LEV and IRR to have declined by R82 736 ha^{-1} and 9% respectively for RM1 and RM4 research trials. Similarly, LEV and IRR declined by R45 750 ha^{-1} and 7% respectively for RM3 and RM4 research trials. Therefore, one could argue that a decline in site productivity due to soil compaction cause by harvesting and residue management can lead to a reduction in financial gains. Considering that, there was a significant drop in estimated financial returns for successive RM research trials.

Predicted financial returns for VCM research trials justified the additional investment made towards vegetation management. Although, manual vegetation control had higher returns than other vegetation management techniques. Coppice management returns were directly propositional to treatment costs, as there were no significant differences in rotation volume reported, higher financial returns were observed for cost-effective treatments.

It is evident that determined financial returns from research results are site-specific and therefore the estimated gains should be consider as such. Lastly, the developed generic DCF model proved to be reliable and can further be used to estimate site specific financial returns by making the necessary change to the input variables.

6.2. LIMITATIONS OF THE RESEARCH STUDY

Limitations of the study were as follows:

- The costs adopted in the study are estimated based on Forestry Economic Services (FES) cost benchmark report of 2014 and further compounded to 2016 costs using real rates.
- Rotation volumes (m^3 ha^{-1}) were predicted for certain research trials where it was not reported at rotation age. Thus, estimates were obtained from mean annual increments (MAI) from the FES cost benchmark report of 2014.

- The analyses was conducted solely for financial analyses, therefore, the environmental, biological and net-social benefits were not considered.
- The financial analyses could only test what was actually done in the research trial. No integration of results across research trials were conducted that could have resulted in a combination of benefits and further predicting which combination has the best financial results.
- The availability of treatment cost data from research trials, a detailed understanding of what was researched and full research information of the research trials (from beginning to end rotation) could have increase the accuracy of estimated site-specific financial returns (gains).

6.3. RECOMMENDATIONS

Future studies should consider the economic effect they will have upon the application of research findings. Reporting of research results from experimental trials should include a site depended financial analyses study, in order to investigate the impact of research outcomes on the forestry value chain.

Furthermore, for the accurate estimation of site specific financial returns based on the implementation of research findings. The reported results should present tested treatment cost data and yields (volume) at the end of rotation (end of trial). Even though there are no significant differences reported in tested treatments or the treatments yielded poor results, should be fully reported as part of research findings.

Lastly, reported research results should consider accurate presentation of growth and yield information (e.g. DBH, height and volume). Further provide sound understanding of costs difference in the implementation of a perfect trial and the operational effect of growing trees. For instance, faulty operational planting, incorrect application of fertiliser and soil-amended hydrogel (or water) at planting.

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APPENDIX

APPENDIX A

Description of collected documents for trial identification

Collected documents on on-site fertiliser recommendations (FR) research trials

Number Code	ICFR Trial No. (if mentioned)	Authors	Title	Year	Source: ICFR Bulletin Series	ICFR Technical Notes	ICFR Annual reports	Published Articles	Unpublished thesis	Other documents
FR1	**C.82**	du Toit B and Oscroft D	Growth response of a Eucalypt hybrid to fertilisation at planting across five site types in Zululand	2003	**X**					
FR2	**C. 83**	du Toit B and Oscroft D	Growth response of a Eucalypt hybrid to fertilisation at planting across five site types in Zululand	2003	**X**					
FR3	**C.84**	du Toit B and Oscroft D	Growth response of a Eucalypt hybrid to fertilisation at planting across five site types in Zululand	2003	**X**					
FR4	**C.87**	du Toit B and Oscroft D	Growth response of a Eucalypt hybrid to fertilisation at planting across five site types in Zululand	2003	**X**					
FR5	**MRF 1**	Titshall L	Mid- rotation fertilisation of Eucalypt pulpwood plantations; Final results	2013	**X**					
		Titshall L	Identifying sites responsive to mid-rotation fertilisation of eucalypt pulpwood plantations: Some early results	2011		**X**				
FR6	**MRF 4**	Titshall L	Mid- rotation fertilisation of Eucalypt pulpwood plantations; Final results	2013	**X**					

Number Code	ICFR Trial No. (if mentioned)	Authors	Title	Year	Source					
					ICFR Bulletin Series	ICFR Technical Notes	ICFR Annual reports	Published Articles	Unpublished thesis	Other documents
FR6	**MRF 4**	Titshall L	Identifying sites responsive to mid-rotation fertilisation of eucalypt pulpwood plantations: Some early results	2011		**X**				
FR7	**MRF 5**	Titshall L	Mid- rotation fertilisation of Eucalypt pulpwood plantations; Final results	2013	**X**					
		Titshall L	Mid- rotation fertilisation of Eucalypt pulpwood plantations; Final results	2011		**X**				
FR8	**MRF 10**	Titshall L	Mid- rotation fertilisation of Eucalypt pulpwood plantations; Final results	2013	**X**					
		Titshall L	Mid- rotation fertilisation of Eucalypt pulpwood plantations; Final results	2011		**X**				
FR9	**MRF 9**	Titshall L	Mid- rotation fertilisation of Eucalypt pulpwood plantations; Final results	2013	**X**					
		Titshall L	Mid- rotation fertilisation of Eucalypt pulpwood plantations; Final results	2011		**X**				
FR10	**C.54**	du Toit B, Arbuthnot A, Oscroft and Job RA	Mid- rotation fertilisation of Eucalypt pulpwood plantations; Final results	2011		**X**				

Collected documents on forest management focusing on residue management (RM) research trials

Number Code	ICFR Trial No. (if mentioned)	Authors	Title	Year	Source: ICFR Bulletin Series	Source: ICFR Technical Notes	Source: ICFR Annual reports	Source: Published Articles	Source: Unpublished thesis	Source: Other documents
RM1		Smith CW and du Toit B	The effect of harvesting operations, slash management and fertilisation on the growth of a *Eucalyptus* clonal hybrid on a sand soil in Zululand, South Africa	2005				X		
		Rietz DN	Soil compaction and residue management effects in Zululand: Results of the second trial crop at Rattray	2015						X
RM2		Rietz DN and Little KM	Changes in *Eucalyptus grandis x E. camaldulensis* productivity between successive rotations in Zululand, South Africa	2014	X					
RM3	SE26	Smith CW, Little KM and Norris CH	The effect of land preparation at re-establishment on the productivity of fast growing hardwoods	2000	X					
		Smith CW, Little KM and Norris CH	The effect of land preparation at re-establishment on the productivity of fast growing hardwoods	2001				X		
		Smith CW, Little KM and Norris CH	Final results of the first rotation of a residue management trial in Zululand	2002	X					

Number Code	ICFR Trial No. (if mentioned)	Authors	Title	Year	Source					
					ICFR Bulletin Series	ICFR Technical Notes	ICFR Annual reports	Published Articles	Unpublished thesis	Other documents
RM4	K7	Rietz DN, Smith CW and Hughes JC	Residue management and compaction effects on the early growth of *Eucalyptus grandis* on a sandy soil in Zululand	2006	X					
		Rietz DN, Smith CW and Hughes JC	Effect of compaction and residue management on soil bulk density and strength at two contrasting sites in Kwazulu-Natal	2010	X					
		Rietz DN	The effect of compaction and residue management on soil properties and growth of *Eucalyptus grandis* at two sites in KwaZulu-Natal, South Africa	2010					X	
		Rietz DN	Soil compaction and residue management effects in Zululand: Results of the second trial crop at Rattray	2015						X
		Rietz DN and Smith CW	Does soil compaction and reside management affect early *Eucalyptus* tree growth on contrasting sites?	2010		X				

Collected documents on forest management focusing on vegetation and coppice management (VCM) research trials

Number Code	ICFR Trial No. (if mentioned)	Authors	Title	Year	Source: ICFR Bulletin Series	ICFR Technical Notes	ICFR Annual reports	Published Articles	Unpublished thesis	Other documents
VCM1		Little KM, Schumann AW and Noble AD	Performance of a *Eucalyptus grandis* x *E. camaldulensis* hybrid clone as influenced by a cowpea cover-crop	2002				**X**		
VCM2		Little KM and Rolando CA	Post-establishment vegetation control in a *Eucalyptus grandis x E. camaldulensis* stand	2002				**X**		
VCM3		Little KM	The response of a Eucalyptus hybrid clone to weed control and burning	2002				**X**		
VCM4		Little KM and van Staden J	Effects of vegetation control on *Eucalyptus grandis x E. camaldulensis* volume and economics	2005				**X**		
		Little KM and can Staden J	Interspecific competition effects early growth of a *Eucalyptus grandis x E. camaldulensis* hybrid clone in Zululand, South Africa	2003				**X**		
		Little KM	The influence of vegetation control on the growth and pulping properties of a *Eucalyptus grandis x camaldulensis* hybrid clone	1999					**X**	
		Little KM, van Staden J and Clarke GPY	The relationship between vegetation management and the wood and pulping properties of a *Eucalyptus* hybrid clone	2003				**X**		
		Little KM, van Staden J and Clarke GPY	*Eucalyptus grandis x E. camaldulensis* variability and intra-genotypic competition as a function of different vegetation management treatments	2003				**x**		

Number Code	ICFR Trial No. (if mentioned)	Authors	Title	Year	Source					
					ICFR Bulletin Series	ICFR Technical Notes	ICFR Annual reports	Published Articles	Unpublished thesis	Other documents
VCM5		Little KM	Final results from a *Eucalyptus grandis x E. camaldulensis* coppice trial	2007				**X**		
VCM6		Little KM and du Toit B	Management of *Eucalyptus grandis* coppice regeneration of seedling parent stock in Zululand, South Africa	2003				**X**		
VCM7		Little KM, Maxfield M and Kritzinger J	Control of *Eucalyptus grandis* cut stumps	1998	**X**					
		Little KM and Eccles NS	Control of *Eucalyptus grandis* cut- stumps of single - stem origin	2000				**X**		
VCM8	**T.111**	Noble AD, Schumann AW, de Laborde RM and Ramsden R	The effect of intercropping cowpeas (*Vigna unguiculata*) on the growth of *Eucalyptus grandis* on the Zululand coastal plain	1991			**X**			
		Eccles NS and Little KM	Final recommendations for cowpea intercropping as a vegetation management tool in Zululand	1995	**X**					
VCM9	**CP161090**	Noble AD, Schumann AW, de Laborde RM and Ramsden R	The effect of intercropping cowpeas (*Vigna unguiculata*) on the growth of *Eucalyptus grandis* on the Zululand coastal plain	1991			**X**			
		Eccles NS and Little KM	Final recommendations for cowpea intercropping as a vegetation management tool in Zululand	1995	**X**					

Number Code	ICFR Trial No. (if mentioned)	Authors	Title	Year	Source					
					ICFR Bulletin Series	ICFR Technical Notes	ICFR Annual reports	Published Articles	Unpublished thesis	Other documents
VCM10		Little KM and Oscroft D	Coppice growth as influenced by damage occurring during reduction operations and control of secondary coppice regrowth	2010		**X**				
VCM11		Bredenkamp BV	Results of an *Eucalyptus grandis* coppice reduction trial in Zululand	1991						**X**

Collected documents on forest management focusing on *Eucalyptus* regeneration (ER) research trials

Number Code	ICFR Trial No. (if mentioned)	Authors	Title	Year	Source					
					ICFR Bulletin Series	ICFR Technical Notes	ICFR Annual reports	Published Articles	Unpublished thesis	Other documents
ER1		Viero PWM, Little KM and Oscroft DG	Establishment of *Eucalyptus grandis x camaldulensis* clones in Zululand: the effect of a soil-amended hydrogel	2000	**X**					
		Viero PWM, Little KM and Oscroft DG	The effect of a soil- amended hydrogel on the establishment of a *Eucalyptus grandis x E. camaldulensis* clone grown on the sandy soils	2000				**X**		
ER2		Viero PWM and Little KM	Influence of a hydrogel on initial Eucalypt growth and root development: Results from a pot trial	2003	**X**					
ER3		Fuller GM and Little KM	Fourteen month responses of *Eucalyptus grandis* micro- cuttings and seedlings and their interaction with weeding in Zululand, South Africa	2007	**X**					

Number Code	ICFR Trial No. (if mentioned)	Authors	Title	Year	Source					
					ICFR Bulletin Series	ICFR Technical Notes	ICFR Annual reports	Published Articles	Unpublished thesis	Other documents
ER3		Viero PWM and Button GA	Eucalypt re- establishment using water or hydrogel in comparison to dry planting for then trials in South Africa	2007	**X**					
ER4		Viero PWM, Chiswell KEA and Theron JM	The effect of a soil- amended hydrogel on the establishment of a *Eucalyptus grandis* clone on a sandy clay loam soil in Zululand during winter	2002				**X**		
ER5		Viero PWM, Rolando CA and Little KM	The interaction between water availability and pit size on early Eucalypt survival and growth	2008	**X**					
ER6		Viero PWM and Button GA	Eucalypt re- establishment using water or hydrogel in comparison to dry planting for then trials in South Africa	2007	**X**					
ER7		Viero PWM and Button GA	Eucalypt re- establishment using water or hydrogel in comparison to dry planting for then trials in South Africa	2007	**X**					
		Viero PWM and Little KM	Eucalypt re- establishment using water or hydrogel in comparison to dry planting for then trials in South Africa	2006				**X**		
ER8		Viero PWM and Button GA	Eucalypt re- establishment using water or hydrogel in comparison to dry planting for then trials in South Africa	2007	**X**					

APPENDIX B

Description of cost data for generic DCF model

The following operational costs were obtained from the Forest Economic Services (FES) cost data for 2014, further adjusted to 2016 costs (as mentioned in Chapter 3). The costs include the land value, general annual costs (GAC) and other operational costs (e.g. planting and weeding). These are further illustrated in the table below, costs are expressed in rand per hectare (R ha^{-1}) and pulpwood sales price (R ton^{-1}) was not adjusted as the 2016 pulpwood prices were used.

Input	FES Cost 2014 (R ha^{-1})	FES Cost 2014 adjusted to 2016 (R ha^{-1})
Land	12 184	13 568
GAC	2 087	2 325
Land preparation	2 254	2 511
Planting	2 488	2 771
Blanking	514	572
Fertiliser	454	506
Weeding	664	740
Harvesting	79 559	88 596
Sales		204 831

The generic discounted cash-flow (DCF) table included the value of land at year zero as a cost and as a revenue at rotation age, as the value of land is regarded as an opportunity cost (Ham and Jacobs, 2012).

The table below gives a description of all the cost includes as part of the GAC:

General Annual Costs derived from:		R ha^{-1}
Forest Protection	Control pests and noxious weeds	114
	Fire protection and insurance	390
	Fire-fighting	36
	Conservation and environment	116
Forest overheads	Hand tools	159
	Building maintenance	61
	Maintenance of other improvements	31
	Administration	1 179
	Community development	3
Total General Annual Costs		**2 087**

For harvesting costs and volume an average rotation age of 9.9 (10) years, a mean annual increment (MAI) of 15.54 ton ha^{-1} was used (FES, 2014).

<u>Other operational activities</u>

Operational activities included land preparation, planting, blanking, fertiliser and weeding costs were included in the DCF model. The operational costs were also adjusted. Furthermore, the table below gives a description of rotation volume and harvesting cost calculations, these include transportation to mill and a price of R750 ton^{-1} delivered to the pulp mill.

Harvesting Roadside	115	R ton^{-1}
Transport (Roadside to mill)	176	R ton-1
Total harvesting costs	291	R ton-1
Pulpwood sales	750	R ton-1
Mean annual increment	16	t ha^{-1} yr^{-1}
Rotation age	10	yr
Rotation volume	155	t ha^{-1}
Total harvesting costs at 155 t ha^{-1}	45 270	R ha^{-1}
Pulpwood sales at 155 t ha^{-1}	116 550	R ha^{-1}

APPENDIX C

Description of cost data used for DCF models

Sources of Cost Data used for treatments in the research trials

Labour costs obtained from the government gazette published on 03 February 2016 as follows:

- Minimum rate for the period 01 March 2016 to 28 February 2017 at R2 779 monthly
- Daily rate at R128
- Hourly rate at R14

Prices for fertiliser costs were estimated from Kaap Agri Bedryf Beperk for September 2016.

Prices for herbicide were obtained from Ecoguard Biosciences for 2016.

Different seedling prices for 2016 were obtained from:

- Sutherland seedlings.
- Zululand nurseries.
- Eshowe nursery.

Other operational and production costs were obtained from anonymous contractor estimates, these include:

- Clearing prior to planting
- Planting
- Blanking
- Fertilisation
- Weeding
- Manual, ripping and mechanical site preparation.

Soil-amended hydrogel costs estimates obtained from Stocksorb Evonika Africa (Pty) Ltd.

Water prices estimates obtained from Ethekwini metropolitan municipality.

Labour costs used per hectare depending on treatment

Labour for planting:

- Mandays ha^{-1} at 2.2; labour cost of R128 ha^{-1}; total cost of R282 ha^{-1}.

Labour for application of fertiliser:

- Mandays ha^{-1} at 1.2; labour cost of R128 ha^{-1}; total cost of R154 ha^{-1}.

Labour cost for clearing prior to planting

- Mandays ha $^{-1}$ at 2.5; labour cost of R128 ha^{-1}; total cost of R321 ha^{-1}.

Labour for manual weed control techniques:

- Mandays ha^{-1} at 2.6; labour cost of R128 ha^{-1}, total cost of R334 ha^{-1}.

Assumptions made on the DCF model costs depending on tested treatment(s)

Burning costs prior to planting were assumed to be the same as clearing costs prior to planting at a cost of R320 ha^{-1}.

Ring weeding (0.5 m radius), inter-row weeding (1.2 m width) and row-weeding (1.2 m width). All assumed manual weed control cost to be the same at R334 ha^{-1}.

Coppice reduction at 1.2 m, 2 m, 4 m, 7 m and 8 m; manual control for secondary growth of coppice and manual bashing of coppice assumed to be the same as manual weed control cost of R334 ha^{-1}.

APPENDIX D

Description of Meta-Analysis framework results

On-Site Specific Fertiliser Recommendation Research Trials

No. Code.	Trial No.	Established date	Trial duration	Species	Treatment details	Yield: Volume (m^3ha^{-1})
FR1	C.82	June 1994	6.5	*E. grandis x urophylla*	T1 [Control]: N 0 g + P 0 g + S 0 g	329
					T2: N 0 g + P 21 g + S 0 g	317
					T3: N 50 g + P 0 g + S 0 g	330
					T4: N 50 g + P 0 g + S 24 g	352
					T5: N 50 g + P 10.5 g + S 21 g	373
					T6: N 50 g + P 21 g + S 42 g	377
					T7: N 100 g + P 10.5 g + S 69 g	370
FR 2	C.83	June 1994	6.5	*E. grandis x urophylla*	T1 [Control]: N 0 g + P 0 g + S 0 g	365
					T2: N 0 g + P 21 g + S 0 g	408
					T3: N 50 g + P 0 g + S 0 g	390
					T4: N 50 g + P 0 g + S 24 g	413
					T5: N 50 g + P 21 g + S 42 g	386
					T6: N 100 g + P 10.5 g + S 21 g	418
					T7: N 100 g + P 10.5 g + S 69 g	393
FR 3	C.84	June 1994	6.5	*E. grandis x urophylla*	T1 [Control]: N 0 g + P 0 g + S 0 g	329
					T2: N 0 g + P 21 g + S 0 g	367
					T3: N 50 g + P 0 g + S 0 g	368
					T4: N 50 g + P 0 g + S 24 g	364
					T5: N 50 g + P 21 g + S 42 g	354
					T6: N 100 g + 10.5 g + S 21 g	378
					T7: N 100 g + P 10.5 g + S 69 g	379
FR 4	C.87	June 1994	6.5	*E. grandis x urophylla*	T1 [Control]: N 0 g + P 0 g + S 0 g	357
					T2: N 0 g + P 21 g + S 0 g	395
					T3: N 50 g + P 0 g + S 0 g	398
					T4: N 50 g + P 0 g + S 24 g	386

No. Code.	Trial No.	Established date	Trial duration	Species	Treatment details	Yield: Volume (m^3ha^{-1})
					T5: N 500 g + P 21 g + S 42 g	392
					T6: N 100 g + P 10.5 g + S 21 g	392
					T7: N 100 g + P 10.5 g + S 69 g	429
FR 5	MRF1	May 2003	6.8	*E. grandis x urophylla*	T1 [Control]: No fertilization	307
					T2: N + P + K [NPK]	300
					T3: N + P + K + Ca + Mg + B + Cu + Zn [NPK+]	311
FR 6	MRF4	March 1999	11	*E. grandis x camaldulensis*	T1 [Control]: No fertilization	203
					T2: N + P + K [NPK]	179
					T3: N + P + K + Ca + Mg + B + Cu + Zn [NPK+]	193
FR 7	MRF5	April 2004	6.95	*E. grandis x camaldulensis*	T1 [Control]: No fertilization	279
					T2: N + P + K [NPK]	270
					T3: N + P + K + Ca + Mg + B + Cu + Zn [NPK+]	253
FR 8	MRF10	February 2003	8.1	*E. grandis*	T1 [Control]: No fertilization	153
					T2: N + P + K [NPK]	154
					T3: N + P + K + Ca + Mg + B + Cu + Zn [NPK+]	166
FR 9	MRF9	October 2008	12	*E. grandis x nitens*	T1 [Control]: No fertilization	188
					T2: N + P + K [NPK]	195
					T3: N + P + K + Ca + Mg + B + Cu + Zn [NPK+]	194
FR10	C.54		8.3	*E. grandis*	T1 [Control]: No fertilization	137
					T2: Agrofert 40 Kg N per Ha	188
					T3: Agrofert 40 Kg N per ha + 40 Kg N per Ha	231
					T4: Agrofert 80 Kg N per Ha	264
					T5: Agrofert 80 Kg N per Ha + 80 Kg N per Ha	227

No. Code.	Trial No.	Established date	Trial duration	Species	Treatment details	Yield: Volume (m^3ha^{-1})
					T6: Humac 40 Kg N per Ha	192
					T7: Humac 40 Kg N per Ha + 40 Kg N per Ha	235
					T8: Humac 80 Kg N per Ha	206
					T9: Humac 80 Kg N per Ha + 80 Kg N per Ha	223

On-Site fertiliser recommendation trials: Significant differences between trial treatments and low, average and high treatment improvements

No. Code of trial	Significant differences in Rot.Vol between treatments		Treatment improvement (TI) compared to control treatment (%)		
	Yes	**No**	**Lowest TI**	**Average TI**	**Highest TI**
FR1	X		-4% (Treatment 2)	7%	15% (Treatment 6)
FR2	X		6% (Treatment 5)	10%	15% (Treatment 6)
FR3	X		8% (Treatment 4)	12%	15% (Treatment 7)
FR4	X		8% (Treatment 5 & Treatment 6)	12%	20% (T7)
FR5		X	-2% (Treatment 2)	0	1% (Treatment3)
FR6		X	-12% (Treatment 2)	-9%	-5% (Treatment 3)
FR7		X	-9% (Treatment 3)	-6%	-3% (Treatment 2)
FR8		X	0 (Treatment 2)	4%	9% (Treatment 3)
FR9		X	3% (Treatment 3)	3%	3% (Treatment 2)
FR10	X		38% (Treatment 2)	62%	93% (Treatment 4)

Forest Management Focusing on Residue Management Research Trials

No. Code.	Trial No.	Established date	Trial duration	Species	Treatment details	Yield: Volume (m^3ha^{-1})
RM1		May 1997	7.25	*E. grandis x camaldulensis*	MB: Manual felling + Broadcast	240
					MW: Manual felling + Windrowed	240
					TH: Tracked Harvester + Semi-windrowed	230
					WH: Wheeled Harvester	260
					F0: No fertiliser [Control]	240
					F1: 233 g/tree [45 g/tree N + 18 g/tree P]	245
					F2: 155 g/tree [30 g/tree N + 12 g/tree P]	250
					F3: 300 g/tree [45 g/tree N + 30 g/tree P]	253
					F4: 200 g/tree [30 g/tree N + 20 g/tree P]	245
RM2		June 2001	7.3	*E. grandis x camaldulensis*	T1 [Control]: No burn + No Fertiliser	100
					T2: Burnt + No Fertiliser	90
					T3: No burn + Fertiliser	120
					T4: Burnt + Fertiliser	110
RM3	SE26	September 1992	8.3	*E. grandis x camaldulensis*	T1 [Control]: No burn + Manual Pitting + No Fertiliser	215
					T2: No burn + Manual pitting + Fertiliser	193
					T3: No burn + Mechanical pitting + No fertiliser	194

No. Code.	Trial No.	Established date	Trial duration	Species	Treatment details	Yield: Volume (m^3ha^{-1})
					T4: No burn + Mechanical pitting + Fertiliser	212
					T5: No burn + Ripping + No fertiliser	188
					T6: No burn + Ripping + Fertiliser	189
					T7: Burnt + Manual pitting + No fertiliser	173
					T8: Burnt + Manual pitting + Fertiliser	177
					T9: Burnt + Mechanical pitting + No fertiliser	211
					T10: Burnt + Mechanical pitting + Fertiliser	184
					T11: Burnt + Ripping + No fertiliser	182
					T12: Burnt + Ripping + Fertiliser	181
RM4	K7	September 2004	7.7	*E. grandis clone (TAG14)*	Low Compaction	196
					Moderate Compaction	195
					High Compaction	195
					Residue Broadcast	195
					Residue Windrow	196
					Residue Removed	193

Residue Management trials: Significant differences between trial treatments and low, average and high treatment improvements

No. Code of trial	Significant differences in Rot.Vol between treatments		Treatment improvement (TI) compared to control treatment (%)		
	Yes	**No**	**Lowest TI**	**Average TI**	**Highest TI**
RM1		X	-4% (Tracked Harvesting)	2%	8% (Wheeled Harvesting)
RM2	X		-10% (Treatment 2)	7%	20% (Treatment 3)
RM3		X	-16% (Treatment 12)	-12%	-1% (Treatment 4)
RM4		X			

Forest Management Focusing on Vegetation and Coppice Management Research Trials

No. Code.	Trial No.	Established date	Trial duration (years)	Species	Treatment details	Yield: Volume (m^3ha^{-1})
VCM1		October 1999	7	*E. grandis x camaldulensis*	T1: Weedy check + Method none	161
					T2: Weedy-free check + Manual weed control	207
					T3: Cowpeas single row 1.5 m from tree rows cowpea cover-crop + Manual	168
					T4: Cowpeas single row 1.5 m from tree rows + herbicide combination of Metolachlor and Paraquat was sprayed in inter-row after cowpeas cover-crop + Chemical + Manual	197
					T5: Cowpeas planted in a double row 1 m from tree rows Cowpeas cover-crop + Manual	178
					T6: Cowpeas planted in a double row 1 m from tree rows + Herbicide combination of metolachlor and Paraquat was sprayed in the inter-	192

No. Code.	Trial No.	Established date	Trial duration (years)	Species	Treatment details	Yield: Volume (m^3ha^{-1})
					row after the cowpeas were planted Cowpeas cover-crop + Chemical + Manual	
VCM2		April 1996	7	*E. grandis x urophylla*	T1: Imposed at 2 years + kept weed free for 7 years + 0-year weedy state before weeding	
					T2: Imposed at 3 years + kept weed free for 6 years + 1-year weedy state before weeding	
					T3: Imposed at 4 years + Kept weed free for 5 years + 2-year weedy state before weeding	
					T4: Complete vegetation control with glyphosate (4l/ha) when required; Unburnt + Weed free	
					T5: Imposed at 6 years + Kept weed free for 7 years + 4 years weedy state before weeding	
					T6: Selective control of all broadleaved vegetation with MCPA (2.5 l/ha) when required such that only grasses remain; Unburnt + Grass	
VCM3		July 1995	7	*E. grandis x camaldulensis*	T1: No weed control; Burnt + Weedy	195
					T2: Complete vegetation control with glyphosate (4l/ha) when required; Burnt + Weed free	269
					T3: No weed control; Unburnt + Weedy	213
					T4: Complete vegetation control with glyphosate (4l/ha) when required; Unburnt + Weed free	275
					T5: Control of all vegetation for 1 m on either side of the tree row with glyphosate (4l/ha) when required; Unburnt + 2 m row weeding	266

No. Code.	Trial No.	Established date	Trial duration (years)	Species	Treatment details	Yield: Volume (m^3ha^{-1})
					T6: Selective control of all broadleaved vegetation with MCPA (2.5 l/ha) when required such that only grasses remain; Unburnt + Grass	220
					T7: Selective control of all grasses with fluazifop-P_butyl (4l/ha) when required such that only broadleaved vegetation remains; Unburnt + Broadleaves	227
VCM4		October 1990	7	*E. grandis x camaldulensis*	T1: Non-weeded control; none	138
					T2: Weed free; Manual	224
					T3: Weed free; Chemical	191
					T4: Inter-row weeding (1.2 m width); Manual	169
					T5: Ring weeding (0.5 m radius); Manual	196
					T6: Complete weeding except ring weeding; Manual	208
					T7: Row weeding (1.2 m width); Manual	186
					T8: Cover-crop with weeding to establish; Cowpea	158
					T9: Cover-crop with weeding to establish; Velvet bean	161
VCM5		September 1992	7	*E. grandis x camaldulensis*	T1: 2 m + 7 m; No control; Weedy	165
					T2: 2 m + 7 m; No control; Weed control	
					T3: 2 m + 7 m; Manual when 0.75 m high; Weedy	
					T4: 2 m + 7 m; Manual when 0.75 m high; Weed control	

No. Code.	Trial No.	Established date	Trial duration (years)	Species	Treatment details	Yield: Volume (m^3ha^{-1})
					T5: 2 m + 7 m; Sprayed with glyphosate at 0.6% when 0.75 m high; Weedy	
					T6: 2 m + 7 m; Sprayed with glyphosate at 0.6% when 0.75 m high; Weed control	
					T7: 4 m + 7 m; No control; Weedy	
					T8: 4 m + 7 m; No control; Weed control	
					T9: 4 m + 7 m; Manual when 0.75 m high; Weedy	
					T10: 4 m + 7 m; Manual when 0.75 m high; Weed control	
					T11: 4 m + 7 m; Sprayed with glyphosate at 0.6% when 0.75 m high; Weedy	
					T12: 4 m + 7 m; Sprayed with glyphosate at 0.6% when 0.75 m high; Weed control	
VCM6		1992	8	*E. grandis*	T1: 4 m + 8 m; Manual removal when 0.75 m high; control	276
					T2: 1.5 m + 8 m; Manual removal when 0.75 m high	
					T3: 4 m + 8 m; Sprayed with glyphosate @ 0.6% when 0.75 m high	
					T4: 4 m + 8 m; Sprayed with Paraquat @ 0.4% when 0.75 m high	
					T5: 4 m + 8 m; Broadcast application of 321 kg/ha of fertiliser at 4:1:1 (N:P:K); manual removal when 0.75 m high	
					T6: Chemical control of all vegetation with glyphosate at 4 l/ha;	

No. Code.	Trial No.	Established date	Trial duration (years)	Species	Treatment details	Yield: Volume (m^3ha^{-1})
					manual removal of secondary coppice regrowth when 0.75 m high	
VCM7		1994		*E. grandis*	T1 [Control]: No burn + Manual bashing	
					T2: Burn + Manual bashing	
					T3: Metsulfuron-methyl + Water + 600 g/kg + 80 g/100 l + Actipron + Foliar spray	
					T4: Triclopyr (butoxy ethyl ester) + Water + 480 g/kg + 750 ml/100 l + Actipron + Foliar spray	
					T5: Glyphosate trimesium + water + 720 g/l + 3.33 l/100 l + Add 2 + cut surface spray	
					T6: Triclopyr (amine salt) + water + 360 g/l + 3 l/100l + Actipron super + cut surface spray	
					T7: triclopyr (butoxy ethyl ester) + diesoline + 480 g/l + 2 l/100 l + cut surface spray	
VCM8	T.111	August 1989		*E. grandis*	T1 [Control]: Weed free control + Manual	
					T2: Weedy	
					T3: Cowpeas + Single row planted at 1.5 m from tree row + intra-row spacing of 0.15 m + density of 7 333 plants per hectare	
					T4: Cowpeas + Double row planted 1 m apart + 1 m from the ree row with the same intra-row escapement + density of 15 666 plants per hectare	
VCM9	CP161090				T1: Weedy control	

No. Code.	Trial No.	Established date	Trial duration (years)	Species	Treatment details	Yield: Volume (m^3ha^{-1})
		October 1990		*E. grandis x camaldulensis*	T2: Cowpeas planted in a single row + 1.5 m from tree rows	
					T3: Cowpeas planted in a double row + 1 m from tree rows	
					T4: Cowpeas planted in a single row + 1.5 m from tree rows + spray metolachlor (Falcon) + Paraquat (Gramoxone) (2.5 + 2.0 l/ha product) stiker (0.5 l/ha)	
					T5: Cowpeas planted in a double row, 1 m from tree rows + spray metolachlor (Falcon) + Paraquat (Gramoxone) (2.5 + 2.0 l/ha product) and sticker (0.5 l/ha)	
					T6: Weed free	
VCM10		2005		*E. grandis x camaldulensis*	T1: No damage + at the time of second coppice reduction	
					T2: No damage + when secondary coppice growth controlled	
					T3: Slight damage + at time of second coppice reduction	
					T4: Slight damage + when secondary coppice regrowth controlled	
					T5: Severe damage + at times of second coppice reduction	
					T6: Severe damage + secondary regrowth controlled	
VCM11		August 1978	10.5	*E. grandis*	T1 [Control]: Reduced to 2 stems per stool	405
					T2: Reduced to 1 stem per stool	408
					T3: Shoots below a predetermined minimum DBH were removed	437

Vegetation and Coppice management trials: Significant differences between trial treatments and low, average and high treatment improvements

No. Code of trial	Significant differences in Rot.Vol between treatments		Treatment improvement (TI) compared to control treatment (%)		
	Yes	No	Lowest TI	Average TI	Highest TI
VCM1		X	5% (Treatment 3)	17%	29% (Treatment 2)
VCM2		X			
VCM3	X		9% (Treatment 3)	26%	41% (Treatment 2)
VCM4	X		15% (Treatment 8)	35%	62% (Treatment 2)
VCM5		X			
VCM6		X			
VCM7	X				
VCM8		X			
VCM9		X			
VCM10		X			
VCM11		X	1% (Treatment 2)	4%	8% (Treatment 3)

Forest Management Focusing on *Eucalyptus* Regeneration Research Trials

No. Code.	Trial No.	Established date	Trial duration (years)	Species	Treatment details	Survival percentage [Dap]
ER1					T1 [Control]: 0 ml water+ 0 g hydrogel	71 [80]
					T2: 500 ml water + 3 g hydrogel	90 [80]
					T3: 500 ml water + 12 g hydrogel	90 [80]
					T4: 1 000 ml water + 9 g hydrogel	90 [80]
					T5: 5 000 ml water + 3 g hydrogel	90 [80]
					T6: 5 000 ml water + 12 g hydrogel	90 [80]
ER2		September 2000	0.11	*E. grandis*	T1 [Control]: 0 ml water + 0 g hydrogel	
					T2: 500 ml water + 0 g hydrogel	
					T3: 500 ml water + 3 g hydrogel	
					T4: 500 ml water + 6 g hydrogel	
					T5: 1 000 ml water + 0 g hydrogel	
					T6: 1 000 ml water + 3 g hydrogel	
					T7: 1 000 ml water + 9 g hydrogel	
ER3		May 2001	1.1	*E. grandis*	T1: Micro-cuttings + Weeding 0 m	
					T2: Micro-cuttings + Weeding 0.9 m	
					T3: Micro-cuttings + Weeding 1.8 m	
					T4: Micro-cuttings + Weeding 2.7 m	
					T5: Seedlings + Weeding 0 m	
					T6: Seedlings + Weeding 0.9 m	
					T7: Seedlings + Weeding 1.8 m	
					T7: Seedlings + Weeding 1.8 m	
ER4		July 1999	0.3	*E. grandis*	T1: 4 000 ml water	50 [118]
					T2: 500 ml water + 3 g hydrogel	67 [118]
					T3: 1 000 ml water + 6 g hydrogel	100 [118]
					T4: 2 000 ml water + 12 g hydrogel	100 [118]
ER5	W202_06	June 2006	0.87	*E. grands x urophylla*	T1:0 ml water	73 [316]
					T2: 1 000 ml water	83 [316]
					T3: 2 000 ml water	83 [316]
					T4 1 000 ml water + 3 g hydrogel	74 [316]

No. Code.	Trial No.	Established date	Trial duration (years)	Species	Treatment details	Survival percentage [Dap]
ER6		November 1998	0.25	*E. grandis x camaldulensis*	T1 [Control]: Dry planting no water	71 [91]
					T2: 1 000 ml water	92 [91]
					T3: Hydrogel 3 g in 1 000 ml of water	100 [91]
ER7		October 2002	0.5	*E. grandis x urophylla*	T1: Dry planting no water [Control]	91 [182]
					T2: 1 000 ml water	95 [182]
					T3: Hydrogel 3 g in 1 000 ml of water	100 [182]
ER8		June 2006	0.67	*E. grandis x urophylla*	T1: Dry planting no water [Control]	90 [244]
					T2: 1 000 ml water	86 [244]
					T3: Hydrogel 3 g in 1 000 ml of water	84 [244]