Current status of technology-use for plantation re-establishment in South Africa

Muedanyi M Ramantswana[12], Michal P Brink[12], Keith M Little[2], Raffaele Spinelli[3] and Paxie WC Chirwa[1]

[1]Forest Science Postgraduate Programme, Department of Plant and Soil Science, University of Pretoria, Pretoria, South Africa

[2]Nelson Mandela University, George, South Africa

[3]CNR IVALSA, Via Madonna del Piano 10, Sesto Fiorentino, Italy

** Corresponding author, e-mail: Muedanyi.ramantswana@mandela.ac.za*

Abstract

Plantation re-establishment is a key component of silviculture as it deals with the creation of a suitable environment when planting or seeding a stand. Re-establishment practices include slash management, site preparation, marking and preparation of a planting position, planting, fertilisation and vegetation management. Over the past decade, there has been a shift towards mechanising re-establishment activities primarily due to labour challenges such as: aging rural workforce; increasing labour costs; high labour turnover; problematic health issues leading to lower productivity; inconsistent work quality by manual labour; and poor ergonomic practices. A survey was conducted to assess and gauge the level of mechanisation within these re-establishment practices in South Africa. Responses to an e-mail questionnaire were received from 43 contractors and 11 grower companies from within the different provinces where commercial forestry is practiced in South Africa. The survey, a first of its kind, was designed and administered following the techniques used in conducting the Forest Engineering technical survey. Descriptive and inferential statistics were used to analyse the data. The results showed that the total area re-planted by respondent contractors and grower companies was ± 36 923 ha–1 per year. The

predominant activities conducted prior to planting comprised: burning (78%); marking a planting position using the baseline method (71%); preparation of a planting position using a road pick (57%) and pre-plant chemical weeding with a knapsack (70%). Furthermore, 45% of planting and 77% of blanking operations were carried out manually with a trowel. Post planting activities such as fertilizing and weeding were carried out through manual spot application of fertiliser (61%) and herbicide application with a knapsack (43%). Overall, the results indicated that typical re-establishment activities are still dominated by manual methods. This study is a baseline for future, periodic surveys that can be conducted to analyse trends and identify areas for improvement in re-establishment activities in South Africa.

Key words: planting, fertilizing, blanking, weeding

Introduction

South Africa has 1 212 383 million ha^{-1} of plantation forests (Forestry South Africa 2019), the majority of which are managed according to an even-aged clearfell silvicultural system. A silviculture system consists of three main functions, which are re-establishment (regeneration), tending and harvesting (Nyland 2002). In South Africa, re-establishment activities are carried out until canopy closure (site capture) and include practices such as residue management (post-harvest slash), site preparation, planting, fertilisation and vegetation management (Theron 2000; Viero and du Toit 2012). It is important that re-establishment practices are carried out optimally as they have a direct impact on tree growth, yield harvested at rotation end and profit (Pallet and Sale 2004). Some of the key objectives of re-establishment in the South African plantation forestry context include ensuring good survival, achieve accelerated growth of healthy trees and maximize stand uniformity (Schönau 1989; Kretzschmar 1991; Little and Rolando 2012).

Mechanised silviculture refers to the change from performing tasks largely or exclusively by hand, to carrying out the task with machinery (Cambridge university press, 2019). In general, mechanised soil preparation is well established for most industrial plantations, with most other operations still manually orientated (Evans and Turnbull 2004). In the South African forestry context, intensive silviculture practices have been investigated since the early 1900's (Lückhoff 1955). In 1938, South Africa had 150 000 ha of commercial forest plantations, by 1975 the total planted area had reached over 1.1 million ha with the focus during this period primarily on the afforestation of virgin grasslands (Owen and van der Zel 2000). Large-scale establishment was achieved during this period because the process of site preparation was highly mechanised. From the mid to late 1900s, afforested grasslands were primarily prepared by ploughing (Poyton 1979; Froehlich 1984), as early research (Schönau 1984) indicated that complete cultivation yielded better growth. The application of complete cultivation by using various mechanised land preparation methods (ploughing, discing, rotovating, ridging, ripping and sub-soiling) on virgin grasslands has been well researched in South Africa (Kretzschmar 1991; Smith et al. 2000). With the transition from establishment to re-establishment, a review of re-establishment techniques indicated that manual pitting combined with weed control was adequate when re-establishing a stand (Smith et al. 2000; Viero and du Toit 2012). As a result, complete site preparation (destumping, discing and ripping) was not recommended under re-establishment conditions, as it was expensive and did not show improved survival and growth (Smith, 2000). From the early 2000s onwards, the focus shifted to more cost efficient pitting methods and implements such as manual pitting and earth augers (Smith et al 2001; Light 2015; Hector 2018) as an alternative to complete cultivation.

Unlike soil preparation, tree planting in South Africa has remained a manual operation over the years (Germishuizen 1982; Viero and du Toit 2012) because of a lack of alternative cost competitive options (Ersson 2014). However, over the past decade and a half, planting tubes and

tractor facilitated planting has been introduced (da Costa 2013). Although mechanised planting is practiced at a small scale when regenerating forest stands in countries such as Sweden and Finland (Ersson 2014; Laine 2017); internationally the adoption of fully mechanised planting machines has not increased because of low cost competitiveness compared to manual planting. This is mainly a result of low productivity, terrain constraints, regular relocation between sites and the need for frequent reloading of planting head with seedlings (Ersson et al. 2018). Furthermore, plantation forestry has been more prevalent in the economic south, where labour is cheaper than in the economic north and thus favouring manual systems.

Post planting activities such as fertilizing and weeding are important for the survival and growth of planted trees. Prior to the advent of herbicides (in particular glyphosate) in South Africa, slashing (manually and mechanically by inter-row cultivation with disc, rotavator or weed-breaker) was carried out to minimise weeds however, the use of herbicides became prominent soon after, as the industry expanded (Gemishuizen 1982). During the early 1990s, hoeing and hand-pulling of weeds along the tree lines was rapidly replaced by the use of herbicides (Schönua et al. 1993). During this period, equipment such as hand-operated knapsack sprayers, motorised mist blowers, controlled droplet applicators (e.g Micron-Herbi; Micron 2019) and tractor-mounted boom sprayers were used for spraying herbicides (Haigh 1987). Currently, intensive vegetation management is primarily based on herbicide applications with limited mechanical, cultural and or biological weed control measures (du Toit et al. 2010). The present emphasis on herbicide application is based on numerous research trials that have shown that the application of herbicides can be used effectively to manage weed competition thus optimising tree growth (Little and Schumann 1996; Little 1999; Little et al. 2018). Modern improvements such as geospatial technologies and variable spray controllers are becoming more important during stand tending operations to improve the efficiency of chemical spraying (Taylor et al. 2002).

Over the past decade, the forestry industry has been subjected to various change drivers (internal or external pressure factors that shape change) that are altering the way forestry activities have traditionally been carried out (Holopainen et al. 2010). These national and international change drivers such as labour issues (Chapman, 2015; McEwan and Steenkamp 2014) and climate change (Pawson et al 2013; Germishuizen 2015) have caused a renewed emphasis on how various forestry activities (including re-establishment) are performed. In South Africa, the shift towards the mechanisation of silviculture over the past decade has mostly been attributed to challenges around labour and include: an aging rural workforce; increasing labour costs; high labour turnover; problematic health issues leading to lower productivity; inconsistent work quality by manual labour; and poor ergonomic practices (Längin and Ackerman 2007; Steenkamp, 2008; Parker 2013, von Benecke 2015). As a result of these challenges, some forestry stakeholders are implementing mechanised re-establishment operations to maintain or improve quality, increase total output, reduce labour requirements, reduce costs, and improve working conditions (Hodgson 1979, da Costa 2013, McEwan and Steenkamp 2014). Due to these factors, it is important to quantify the degree of mechanisation in re-establishment operations and to determine the direction of technology.

Forest technical surveys conducted in the past have focused on assessing harvesting activities and paid very little attention to silvicultural practices (Brink and Warkostch 1990). This forest technical survey focussed on mechanisation in silviculture re-establishment in South Africa's plantation forests by identifying the methods used in performing re-establishment activities and quantifying the area re-established through the following re-establishment practices: residue management, preparation of a planting position, planting, fertilising, and weeding. There is a lack of this type of information and this study will give foresters and managers an insight into available and emerging re-establishment technologies. Furthermore, the data obtained from this survey will

be used as a reference to trace the trends of technology development in re-establishment activities.

Materials and methods

Surveying method

A structured questionnaire approach was used in this study to obtain data to fulfil the study objectives. According to Mathers et al. (2007), questionnaires are the most efficient and cost-effective way to collect data from geographically spread sources. A questionnaire was designed for data collection from both forestry grower companies as well as silvicultural contractors used by these companies. The questionnaire was developed according to the methodology that has been shown to be effective for collecting survey data in previous similar forestry studies (Brink and Warkostch 1990; Brink 2001; Längin and Ackerman 2007; D' Amato et al. 2009). The survey was carried out in accordance with all ethical requirements such as consent, risk, privacy, anonymity, confidentiality, and autonomy (University of Pretoria 2016).

The details of potential participants were obtained from various sources such as available industry databases and the South African forestry contractors association (SAFCA). An estimated 90 percent of all commercial forestry contractors in South Africa are registered with SAFCA (Steenkamp pers. comm. 2018), with 111 silviculture contractors registered on their database. The survey was intended to be a census of all re-establishment methods and resources used by silviculture contractors (SAFCA registered); however, this census could not be achieved, as some of the contractors did not respond (response rates are stipulated under the results section). The questionnaires were distributed electronically via e-mail to the contractors and grower companies (Table 1).

Table 1: Summary of information requested from contractors and grower companies surveyed on forest re-establishment operations.

No	Main sections	Information
1	Background information	Name, position, grower company/ contractor name, experience, province, labour numbers and general terrain conditions
2	Re-establishment area	Total areas re-planted annually per species, regeneration methods and planting densities (spacing)
3	Re-establishment activities and area	Details of methods and annual hectares for the following re-establishment activities: residue management, weeding before plant, preparation of planting position, planting, blanking, fertilizing, weeding after planting
4	Re-establishment resources and area	Details of labour and equipment required to perform the following re-establishment activities: residue management, weeding before plant, preparation of planting position, planting, blanking, fertilizing, weeding after planting

To obtain information from grower companies, the relevant grower company representative was identified and requested to complete the questionnaire. A total of 11 grower companies completed the questionnaire. To facilitate easier data collection form their contractors, three grower companies completed the contractor questionnaires on behalf of their contractors. The information supplied by the three grower companies represented 28 contractors who were part of the SAFCA list. In addition, individual contractors (n = 43) were contacted telephonically or via e-mail and requested to complete the questionnaire. Respondents were asked to complete their responses within three weeks.

Data analysis

Only questionnaires where all responses were completed were considered. The nominal and ordinal data collected was captured under the appropriate column headings on a spreadsheet and summarised for further analysis. Descriptive statistics (means, frequencies and percentages) were derived from the data. The results were summarised and presented according to hectares and corresponding percentages for each activity (Tables). Under general information, percentages are included for the readers benefit, for example: Most respondents (n = 18; 60%) indicated that 18

respondents out of a total sample of 30 provided responses. To further explore the data, inferential statistics were carried out to compare if there were any significant differences in the proportions of area established by a particular re-establishment activity based on species planted and or location (province) of activity. Meaningful comparisons within key re-establishment activities were carried out between eucalypts and pines as they are the two most commonly planted genera in South Africa (Forestry South Africa, 2019), as well as between KwaZulu-Natal and Mpumalanga provinces as they comprise of the largest plantation forestry areas in South Africa (Forestry South Africa, 2019). Cohen's co-efficient were used to determine significance at $p < 0.05$ (Cohen 1988).

Results

General information

The respondents that participated in this survey replanted approximately 36 923 ha in 2018, which represents 59.2% of the 2017 replanted areas. Of the total respondents, 53.1% indicated that they coppice eucalypt stands at least for a rotation before replanting. The species planted within this area were eucalypts (69.8%), pines (29.8%) and acacias (0.5%). The total area replanted with *Acacia* by survey respondents was only 170 ha, which was considered too small to make any meaningful deductions - and as such this data was excluded from further analysis. Most contractor respondents (n = 25; 58%) indicated that the most prevalent slope class range where they conducted re-establishment activities was 12º to 17º (the slope was kept in degrees to avoid confusing the reader between the respondent % and the slope %), whereas 18 (19%) worked on slopes greater than 17º. Most of the areas were replanted during the months from September to May, with the least planting occurring from June to August (Figure 1).

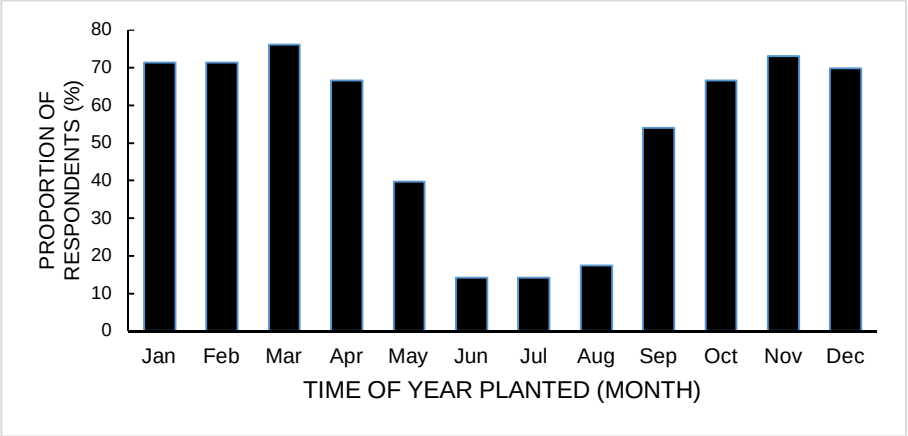

Figure 1: Planting months for plantation re-establishment in South Africa, 2018

The majority of the areas surveyed were in KwaZulu-Natal (47.3%) and Mpumalanga (38.4%) followed by Western Cape (10.3%) and Eastern Cape (4.1%). No response was received from the two contractors contacted in Limpopo province. Limpopo province is relatively small and it comprises of 4.1% of the total plantation forestry area in South Africa (Forestry South Africa 2019). The response rate as a percentage of all SAFCA registered contractors excluding those not involved in re-establishment was 69%.

According to the survey, grower companies and silviculture contractors respectively employed 8 342 (unskilled labour = 89.8%, supervisors = 5.1% and drivers = 5.1%) and 7171 labourers (general labour 90.1%, supervisors = 5.3% and drivers = 4.6%) worker units in re-establishment operations. Grower companies had a higher employment number as some companies carry out re-establishment work in-house. The average age of the contracting business was 15.4 years, ranging from seven months to 40 years.

Re-establishment practices and areas

Residue management

The most common residue management method across all species was controlled burning (78.3%) followed by residue spreading (11%) (Table 2). Of the total area burnt, 24 029 ha were

ex-eucalypt and 8 564 ha ex-pine stands. In contrast, most of the residue spreading was carried out in pine (3 535 ha) stands.

Table 2: Area of residue management, marking and preparation of planting position, weeding managed, and technology-use for plantation re-establishment in South Africa, 2018

Activity	Methods	Area	
		Ha	Proportion of total area (%)
Residue management	Burning	32 764	78.3
	Spreading	4 617	11.0
	Mulching	3 532	8.4
	Biomass removal	576	1.4
	Wind-rowing	254	0.6
	Slewing with single pitting head machine	126	0.3
	Total	41 869	100.0
Marking a planting positon	Manual baseline method	27 042	71.6
	Using old stump-lines	9 136	24.2
	Other (rope, stick, georeferenced by pitting machine)	1 600	4.2
	Total	37 778	100.0
Preparing a planting position	Manual with road pick	22 325	57.2
	Single head pitting machine	6 412	16.4
	Tractor/bulldozer ripping	5 797	14.9
	Earth auger	2 079	5.3
	Wasserplanzer	1 300	3.3
	Multiple head pitting machine	1 100	2.8
	Total	39 013	100.0
Weeding before planting	Manual with chemical spray knapsack	26 884	70.8
	Tractor boom spray (e.g. with lances)	5 439	14.3
	Manual with boom spray	2 773	7.3
	Aerial spray (helicopter/fixed wing)	430	1.1
	Manual chemical spray with electric motorised knapsack	230	0.6
	Other (manual slashing, unmanned aerial vehicle, brushcutters)	2 197	5.8
	Total	37 953	100.0

Marking a planting position

In most cases, the marking of a planting position was carried out manually by setting up a baseline (71.6%) (Table 2). The use of previous rotation stump lines to mark a planting position was more

common in eucalypt than in pine stands. Where marking a planting position was conducted in pine stands, the baseline method constituted 92.1% of the total area (10 358 ha), whilst in re-establishing eucalypts the same method made up 63.1% of the total area (16 624 ha). The respondents indicated that other techniques such as using a rope, stick or tape measure were used at a very limited scale (4.2%) to mark out planting positions.

Figure 2: Semi-mechanised and fully mechanised technologies used in re-establishment (a) Preparation of a planting position with the MPAT single pitting head machine (Ramantswana 2018), (b) Weeding before planting with a tractor-mounted boom sprayer (Ntinga 2019) (c) Planting with a tractor towed trailer planter (Anco manufacturing 2019) and (d) Weeding after planting with a tractor mounted windbox unit (Gumede 2019).

Preparation of a planting position

Manual pitting with a road pick made-up 57.2% of all preparation of planting position methods, on a per hectare basis (Table 2). Of interest, in eucalypt stands, mechanised preparation of a planting position made up 37.5%, semi-mechanised 10.3% and manual 52.2% of the total area prepared

(27 631 ha). In pine stands, mechanised preparation of a planting position (Figure 2a) made up 26.2%, semi-mechanised 3.3% and manual 69.9% of the total area prepared (11 163 ha). A relatively new technology used is the Wasserplanzer, which makes use of high water pressure to bore a planting position.

Weeding before planting

Before planting, most weeding operations were conducted by applying herbicide with knapsack sprayer (70.8%) (Table 2). In eucalypt stands, the tractor-mounted boom spray (Figure 2b) was far more popular (18% of 28 118 ha) than in pine stands (3.9% of 9 724 ha).

Planting

Planting of cuttings and seedlings manually was the main method used, either with a hoe/ trowel (44.6%), or with planting tubes (39.4%) (Table 3). In eucalypt stands, semi-mechanised planting with tractor-towed implements (Figure 2c) made up 19.8% and manual (trowel and planting tubes) 80.2% of the total planted area (25 555 ha). In pine stands, semi-mechanised planting with tractor-towed implements made up 7.5% and manual 92.5% of the total planted area (11 198 ha).

Fertilizing

Over 60% of the trees were fertilized manually using granular type fertilizer (Table 3), with fertilizer tablets applied to 11.6% of the total area fertilized. A fertiliser tablet is a form of water soluble aggregate that slowly dissolves in the pit when applied into the pit. The tablet contains either nutrients, or they are combined with pesticide. Of the total area fertilized during the re-establishment phase, 88.4% was in eucalypt stands.

Table 3: Area of planting, fertilizing, blanking and weeding after planting managed and technology-use for plantation re-establishment in South Africa, 2018

Activity	Methods	Area	
		Ha	Proportion of total area (%)
Planting	Manual hoe/trowel	16 470	44.8
	Planting tube/krupps'	14 389	39.1
	Tractor with towed planter	4 262	11.6
	Self-propelled planter (Fiori)	1 166	3.2
	Wasserplanzer	466	1.3
	Total	36 753	100.0
Fertilizing	Manual	18 090	61.8
	Manual: Fertilizer forks	6 303	21.5
	Fertilizer tablet	3 411	11.6
	Fertilizer backpacks	1 484	5.1
	Total	29 288	100.0
Blanking	Manual hoe/trowel	5 885	77.3
	Planting tube	1 686	22.1
	Tractor with planting trailer	43	0.6
	Total	7 614	100.0
Weeding after planting	Manual knapsack and cones	55 877	43.8
	Manual slashing	28 027	22.0
	Manual hoe (ring weed)	21 957	17.2
	Tractor boom spray/lances	9 355	7.3
	Windboxes	3 456	2.7
	Other (disc plough, tractor drawn slasher, brushcutter)	9 002	7.1
	Total	127 674	100.0

Blanking

Blanking entails the replacement of any dead seedlings soon after planting, to mitigate the effects of mortality and achieve maximum stocking. Most of the blanking was carried out manually using a hoe/trowel (77.3%) (Table 3). Even though most of the areas (4 291 ha) in eucalypt stands were blanked by using a hoe/trowel (68.3%) planting tubes (23.9%) were also used. This link was also noticeable in pine stands (3 322ha) but to a lesser extent (hoe/trowel 89.1%; planting tubes 10.9%).

Weeding after planting

After planting, most of the weeding was conducted manually by using knapsacks alone or together with cones (43.8%) (Trees protected from spray drift by inverted plastic cones) (Table 3). Apart from manual methods, such as slashing (22.0%) and manual ring weeding (removal of a 1 m diameter of weeds around each tree by using a hoe) (17.2%); mechanical methods were used to conduct weeding operations. These mechanical methods included: spraying herbicide with tractor-mounted herbicide sprayers (e.g. wind boxes – Figure 2d), harrowing the inter-rows with tractor-towed disk ploughs, cutting with clearing saws, and aerial spraying.

The inferential statistics indicated that the proportions of areas re-established by the various methods (Annexure 1 and 2) differed significantly between eucalypts and pines except when planting with a planting tube. For mechanisation, the proportion of semi-mechanised and mechanised re-establishment operations was significantly higher for eucalypts than for pines. For example, the mechanised pitting (single pitting head machine) area as a proportion of the total area pitted in eucalypts was 15.4% higher compared to pines (Table 4). These results also indicate that the proportions of areas re-established by the various methods differed significantly for KwaZulu-Natal and Mpumalanga, except for manual slashing of weeds after planting. In terms of mechanisation, the proportion of semi-mechanised and mechanised re-establishment operations was significantly higher in KwaZulu-Natal compared to Mpumalanga province. For example, the area sprayed (chemical) by semi and fully mechanised systems (tractor with wind boxes or lances) as a proportion of the total area sprayed in KwaZulu-Natal was 9.9% higher compared to Mpumalanga (Table 4).

Table 4: Summary of analysis showing significant differences between genus and province in terms of re-establishment practices in South Africa

Re-establishment activity	Method	Genus (Eucalypt and Pine)		Province (KwaZulu-Natal versus Mpumalanga)	
		Cohen's D	P value[1]	Cohen's D	P value[1]
Residue management	Burning	0.350	<0.05	0.496	<0.05
	Spreading	0.722	<0.05	0.375	<0.05
	Mulching	0.109	<0.05	0.104	<0.05
Marking of a planting position	Manual baseline	0.756	<0.05	1.216	<0.05
	Using old stump-lines	0.636	<0.05	0.988	<0.05
Preparation of a planting position	Manual with road pick	0.366	<0.05	0.056	<0.05
	Earth auger	0.121	<0.05	0.199	<0.05
	Single pitting head machine	0.433	<0.05	0.554	<0.05
	Tractor ripping	0.115	<0.05	0.948	<0.05
Weeding before planting	Manual chemical spray with knapsack	0.459	<0.05	0.785	<0.05
	Tractor boom spray	0.514	<0.05	0.927	<0.05
Planting	Manual hoe/trowel	0.233	<0.05	0.178	<0.05
	Planting tube	n/a	0.1786	0.524	<0.05
	Tractor with towed planter	0.258	<0.05	n/a	n/a
Fertilizing	Manual	1.113	<0.05	0.987	<0.05
	Fertilizing forks	n/a	n/a	0.410	<0.05
Blanking	Manual hoe/trowel	0.526	<0.05	1.04	<0.05
	Planting tube	0.505	<0.05	0.977	<0.05
Weeding after planting	Manual slashing	0.282	<0.05	n/a	0.8919
	Manual hoeing	0.142	<0.05	0.363	<0.05
	Chemical spray with knapsack and cones	0.071	<0.05	0.562	<0.05
	Chemical spray with tractor implements	0.107	<0.05	0.315	<0.05
	Inter-row tractor disc	0.034	<0.05	0.351	<0.05

Note: [1] Significant differences between Genus or Province in terms of re-establishment practices are indicated at the 95% level ($p<0.05$)

Discussion

This study's survey showed that the majority of re-establishment activities used by the forest industry are manually orientated. It is also clear that some activities make use of semi-mechanised and fully mechanised operations. According to Evans and Turnbull (2004), rainfall patterns usually determine when trees should be planted. Depending on the region, South Africa receives its rainfall during the

summer and winter months and this period is generally referred to as the planting season (Schönau and Grey 1987). Viero (2000) specifies that conventional planting should take place in the temperate regions between September and May (summer), and to the cooler months between March and October (winter) in the subtropical regions (Zululand). The results from this study confirm that most planting is conducted during the summer season with exception of areas such as Zululand, which are planted during the winter season.

According to Gonçalves et al. (2008), the type and amount of residues that remain on a site directly affect the operational effectiveness of subsequent mechanised re-establishment activities. When the site is free of residues, mechanised activities are uniform due to less obstructions (branches) on the site. The controlled burning of residues is the most common method to reduce residues following harvesting. Even though controlled burning carries a high risk for both labourers and the site, it is still preferred as it is quick and cost efficient compared to available manual and mechanised methods (Evans and Turnbull, 2004). Spreading (broadcasting) residues is a method mainly applied in pine stands before replanting. In certain areas, spreading is also applied to eucalypt stands, even though it requires more effort than in pine stands due to the heavier and denser residues. Mulching is an effective alternative, but its higher cost (Viero and du Toit 2012) represents a barrier to its implementation on a larger scale.

The marking (laying-out) of a planting position prior to planting is an important task because it sets the alignment of planting rows and the spacing between trees (Evans and Turnbull, 2004). To reduce costs, this operation is usually combined with the preparation of a planting position (Viero and du Toit 2012). Survey results indicated that when re-establishing pine stands it is common to use the baseline method to mark planting positions, while in eucalypt stands planting positions are readily located through the old stump lines. The latter method is effective and saves costs as there is no need to mark the stand.

The preparation of a planting position is a labour intensive and expensive operation (van Wyk et al. 2006). Even though the majority of the sampled area is prepared manually with a road pick, there were other methods used to perform this work such as semi-mechanised (power auger) and mechanised (single pitting head and multiple pitting head machines). According to Viero and du Toit (2012), the preparation of a planting position using semi or fully mechanised systems produces consistently better soil friability and pit depth compared to the manual method. According to Parker (2013), mechanised methods of soil preparation have more limitations than manual methods such as an inability to work on steep gradients, and the tractor's inaccessibility to certain areas because of obstacles such as rocks, residues and stumps.

Weeding before planting is commonly known as a pre-plant herbicide spray (Little 2012). In South Africa, the commonly used herbicide is glyphosate (Little and Roland 2012). Sprayers can be manually operated knapsacks, electric powered knapsacks or tractor mounted. The latter is a recent development and consists of applying a large powered sprayer to a tractor. The herbicide is then applied through boom-mounted nozzles or to manually-operated lances. For the latter, five or more people walk behind the tractor and perform directed herbicide application using the lances. This type of technology reduces the physical load of carrying 10 – 20ℓ by the worker and improves overall efficiency, but can only be applied when the sites are accessible to tractors.

There was a difference of only 5.2% (area) between manual planting with a hoe and planting tube methods, with the latter considered more ergonomically friendly and productive (Parker 2013). In South Africa, the Krupps' planter was one of the first planting tube type tools developed to improve planting. When using this tool, the operator drives the lower tip into the pit and inserts the seedling at the top of the tube - followed by a cup of hydrogel if required - and then closes the handles to deposit the contents into the pit. Over the years, the original Krupps' planter design has been improved, leading to the development of a revised version where the backpack containing hydrogel

is connected to the planting tube via a pipe and the operator can release hydrogel into the pit using a dedicated trigger fitted to the tube handle. A semi-mechanised planting system is composed of five to six employees walking behind a water trailer carrying a planting tube and seedlings (Guerra et al. 2019. The system has limited use in South Africa because it is dedicated to flat terrain where slash has been burnt. No fully mechanised planting was reported in this survey, however, globally mechanised planting has been used in Brazil and the Nordic countries (Guerra et al 2019; Laine 2017; Luoranen et al. 2011; Ersson et al. 2014; Hallongren et al. 2014).

The application of fertilizer by hand is time-consuming but advantageous as placement is relatively accurate. Accurate placement during re-establishment is important because placing the fertilizer too close may damage the plants, while placing it too far may make it unavailable to the plant (Evans and Turnbull 2004). Recently, fertilizer forks and backpack applicators have been introduced to improve the efficiency of applying granular fertilizer. Even though these new improved methods are efficient and ergonomically friendlier (labourers do not have to bend) than the manual ones, they are vulnerable to fertilizer clogging when the granular fertilizer is exposed to moisture.

A fully stocked stand is important for realising the full productive potential of a site (Pallet and Machaka 2009). Blanking in South Africa is undertaken to ensure survival is greater than 90% (Schönau and Stubbings 1987). Unlike planting, most blanking operations are conducted manually because of the complexity of machines moving through a planted stand without damaging live seedlings. Semi-mechanised (tractor planter) blanking warrants proper planning prior to use because the machine should travel on designated routes between the planted trees.

Weeding after planting is an important phase during the re-establishment of a stand. Post-establishment weeding operations are conducted several times to reduce the negative impact of vegetation competition on tree growth (Little and Rolando 2012). In South Africa, chemical weed

control is the most widely used and cost efficient method (Little et al. 2001; Little and Rolando 2012), however, other vegetation control methods such as hoeing (ring weeding) and slashing are used to supplement chemical weeding (Savill et al. 1997). Manual weed control methods are labour intensive and only performed in areas in close proximity to the seedling. When removing weeds, damage can be caused to the roots or stem when weeds close to the seedling are removed (Little et al. 2001). The use of portable hand-held machines such as brush cutters and clearing saws is becoming more prominent where the ground conditions and vegetation allow. Other tractor implements such as flails and ploughs can be relatively cost effective but they are only effective for a short period because they slash the weeds but do not kill them (Savill et al. 1997). Furthermore, risk to the young plants can be high unless the operation is carried out very carefully. The survey results showed chemical weeding by knapsacks and manual weeding (slashing and ring hoeing) as the main weeding-after-planting methods, which is consistent with existing literature findings.

Re-establishment still has a relatively low level of mechanisation compared to harvesting in South Africa. There are various reasons why grower companies and contractors select a particular re-establishment method. These reasons can be to improve safety, increase productivity, decrease costs, achieve consistent quality, and be environmental and/or socially friendly (McEwan and Steenkamp 2014; da Costa 2013; Hodgson 1979).

Conclusions

In South Africa, most of the currently used mechanised and semi-mechanised re-establishment technologies are still in their early stages of development. Grower companies and contractors may not completely adopt the mechanised approach because of unsuitable terrain, socio-economic challenges (e.g. job losses) and low utilisation of machinery due to the seasonal nature of re-establishment activities.

This study's results showed that re-establishment activities are still dominated by manually orientated methods such as: controlled burning; marking for pitting by using the baseline method; preparation of a planting position by using a road pick; pre-plant chemical weeding with a knapsack; manual planting and blanking with a trowel; manual spot fertilizing; and chemical application with a knapsack after planting. Overall, the application of semi-mechanised and mechanised tools and systems was more prevalent in eucalypts and KwaZulu-Natal than pine stands and Mpumalanga respectively. In the future, because of labour challenges such as an aging rural workforce, increasing labour costs, high labour turnover, and problematic health issues relating to productivity, quality challenges of manual and unskilled labour, poor ergonomic practices and safety challenges associated with the use of sharp tools, re-establishment mechanisation may become more prevalent.

This study is a baseline for future, periodic surveys that can be used to analyse trends and identify potential areas for improvement in re-establishment activities in South Africa.

Acknowledgements

The authors would like to acknowledge the Nelson Mandela University and FP&M SETA for the research funds. The grower companies and contractors who contributed to the research are also thanked. Samara Maschetti and Nontethelelo Ramantswana are both acknowledged for their assistance in organising the data and for the preliminary analysis. Kirstie Eastwood is acknowledged for her assistance with the statistical analysis of the data.

References

ANCO manufacturing 2019. Tree planting. ANCO Automated planter gallery. Piet retief: ANCO manufacturing.

Brink MP, Warkotsch PW. 1990. South African Forest Technical Survey. *South African Forestry Journal* 152: 72-79.

Brink MP. 2001. Development of a method to forecast future systems in the forest engineering value chain. PhD thesis. Stellenbosch: University of Stellenbosch.

Cambridge University Press. 2019. Definition of mechanization. Available at https://dictionary.cambridge.org/dictionary/english/mechanization [accessed 16 August 2019].

Chapman C. 2015. Mechanisation changing the face or forestry. *SA Forestry magazine* 15 March: 3.

Cohen J. 1988. *Statistical power analysis for the behavioural sciences* (2nd edn). Lawrence Erlbaum Associates: New York.

da Costa D. 2013. Modernising and the effect on Silviculture. Presented at Focus on Forest Engineering conference on Mechanised harvesting and silviculture, Pietermaritzburg, 6 November 2013

D'Amato WA, Bolton NW, Blinn CR, Ek AR. 2009. Status and Long-term Trends of Silvicultural Practices in Minnesota: A 2008 Assessment. *Staff Paper Series No. 205*. St Paul Minnesota: University of Minnesota.

du Toit B, Smith CW, Little KM, Boreham G, Pallett RN. 2010. Intensive, site-specific silviculture: Manipulating resource availability at establishment for improved stand productivity. A review of South African research. *Forest Ecology and Management* 259: 1836–1845.

Ersson BT. 2014. Concepts for Mechanized Tree Planting in Southern Sweden. PhD thesis, Swedish University of Agricultural Science, Sweden.

Ersson BT, Bergsten U, Lindroos O. 2014. Reloading mechanized tree planting devices faster using a seedling tray carousel. *Silva Fennica* 48: 1-12.

Ersson BT, Laine T, Saksa T. 2018. Mechanised tree planting in Sweden and Finland: Current and key factors for future growth. *Forests* 9: 370

Evans J, Turnbull J. 2004. *Plantation forestry in the tropics* (3rd edn). New York: Oxford University Press.

Forestry South Africa. 2019. South African forestry and forest products industry 2017. Available at https://www.forestry.co.za/uploads/File/industry_info/statistical_data/new%20layout/South%20African%20Forestry%20&%20Forest%20Products%20Industry%20-%202017.pdf [accessed 10 April 2019]

Froehlich HA, 1984. Mechanical Amelioration of adverse physical soil conditions in Forestry. In: Grey DC, Schönau APG, Schutz CJ, (eds) *Proceedings of the Symposium on site and productivity of Fast growing plantations, 30 April - 11 May, Pretoria and Pietermaritzburg.* International Union of Forestry Research Organisations. pp 507 – 517.

Germishuizen I. 2015. Climate change: An update on climate projections and their implications for the South African forestry sector. *ICFR Technical Note No. 01/2015*. Pietermaritzburg: Institute for Commercial Forestry Research.

Germishuizen PJ. 1982. Silviculture practice for Pine and Eucalyptus In: Vosloo JJ (eds), *Saasveld 50 (1932 – 1982)*. George: Directorate of Forestry, Department of Environment Affairs. pp 102 – 111.

Gonçalves JLM, Stape JL, Laclau J-P, Bouillet J-P, Ranger J. 2008. Assessing the effects of early silvicultural management on long-term site productivity of fast-growing eucalypt plantations: the Brazilian experience. *Southern Forests* 70: 105–118.

Guerra SPS, Soler RR, Sereghetti GC, Oguri G. 2019. An evaluation of the economics and productivity of fully mechanised tree seedling planting in Brazil. *Southern Forests* 81: 281-284.

Gumede M 2019. Photo: Weeding after planting with a tractor mounted windbox unit Kwambonambi.

Haigh H.1987. Forestry weed control. In von Gadow K, van der Zel DW, van Laar A, Schönau APG, Kassier HW, Warkotsch PW, Vermaas HF, Owne DL, Jordaan JV (eds), *South African Forestry handbook* (2nd edn). Pretoria: South African Institute of Forestry. pp 107 - 108

Hallongren H, Laine T, Rantala J, Saarinen V, Strandstrom M, Hämäläinen J, Poikela A. 2014. Competitiveness of mechanized tree planting in Finland. *Scandinavian Journal of Forest Research* 29: 144–151.

Hector U. 2018. The impact of re-establishment practices on tree survival, growth and uniformity in South African eucalypt plantations. Masters thesis, Nelson Mandela University, South Africa.

Hodgson TJ. 1979. Justification for mechanisation in Silviculture. *South African Forestry Journal* 110:16–19.

Holopainen M, Hyyppä J, Vaario L, Yrjälä K. 2010. Implications of Technological Development to Forestry. In Mery G, Katila P, Galloway G, Alfaro R, Kanninen M, Lobovikov M, Varjo J (eds), *Forests and society – responding to global drivers of change*. International Union of forest research organisation (IUFRO). pp 157 – 176.

Kretzschmar DE, 1991. Site preparation for the growth of Eucalyptus species in South Africa. In: Schönau APG (eds) *Proceedings of the IUFRO symposium Intensive Forestry: The role of Eucalypts, 2 – 6 September. Durban.* International Union of Forestry Research Organisations pp 532 – 535.

Längin D, Ackerman P. 2007. South African Forest Engineering Survey 2006/2007. Stellenbosch: Stellenbosch University & Institute of Commercial Forestry Research. University of Stellenbosch.

Laine T. 2017. Mechanized tree planting in Finland and improving its productivity. PhD thesis, University of Helsinki, Finland.

Light ME. 2015. Plantation re-establishment: principles of pit preparation. *ICFR Technical Note* No. 03/2015. Pietermaritzburg: Institute for Commercial Forestry Research.

Little KM, 1999. The influence of vegetation control on the growth and pulping properties of A *Eucalyptus grandis x camaldulensis* hybrid clone. PhD thesis, University of Natal, South Africa.

Little KM. 2012. The interaction between three pine species and weed competition on two contrasting sites in Mpumalanga, South Africa. *ICFR Bulletin Series* No 04/2012. Pietermaritzburg: Institute for Commercial Forestry Research.

Little KM, Schumann AW. 1996. A new systematic trial design for the optimization of interspecific weed control. In: Sheperd RCH (eds), P*roceedings of the Eleventh Australian Weeds Conference, Frankston,* Weed Science Society of Victoria Inc. pp. 440–444.

Little KM, Roland C. 2012. Vegetation management. In: Bredenkamp BV, Upfold SJ (eds), *South African Forestry handbook* (5th edn). Pretoria: South African Institute of Forestry Research. pp 107 - 112.

Little KM, Kritzinger JL, Higgs G. 2001. Sensitivity of Pinus patula to the application of pre-emergent herbicides at planting. *ICFR Bulletin Series No*. 18/2001. Pietermaritzburg: Institute for Commercial Forestry Research.

Little KM, Ahtikoski A, Morris AR. 2018. Rotation-end financial performance of vegetation control on Eucalyptus smithii in South Africa. *Southern Forests* 80: 241 – 250

Lückhoff HA.1955. The establishment and regeneration of Eucalyptus saligna plantations in the coastal belt of Zululand. *Journal of South African Forestry* 25: 1 - 20

Luoranen J, Rikala R, Smolander H. 2011. Machine planting of Norway spruce by Bracke and Ecoplanter: an evaluation of soil preparation, planting method and seedling performance. *Silva Fennica* 45: 341–357.

Mathers N, Fox N, Hunn A. 2007. Surveys and Questionnaires. The NIHR RDS for the East Midlands / Yorkshire & the Humber. pp 4 - 38

McEwan A, Steenkamp J. 2014. Silviculture modernization in the South African forestry industry. In Ciancio O, *Proceedings of the second international congress of silviculture, 26 - 29 November 2014. Florence.* Accademia Italiana di Scienze Forestali. pp 822 - 826

Micron 2019. Herbiflex 4. Available at http://www.microngroup.com/agricultural/herbiflex-4 [accessed 16 August 2019]

Ntinga N 2019. Photo: Weeding before planting with a tractor-mounted boom sprayer Pietermaritzburg

Nyland RD. 2002. *Silviculture concepts and applications*. (2nd edn). Waveland press: Inc. United states of America.

Owen DL, van der Zel DW. 2000. Trees, Forests and Plantations in Southern Africa In: Owen DL (eds), *South African Forestry handbook* (4th edn). Pretoria: South African Institute of Forestry Research (SAIF). pp 3 – 8.

Pallet RN, Machaka TL. 2009. Individual tree growth differences in a clonal eucalypt blanking trial at four years. *Southern Forests* 71: 95–99.

Pallet RN, Sale G. 2004. The relative contributions of tree improvement and cultural practice towards productivity gains in Eucalyptus pulpwood stands. *Forest Ecology and Management* 193: 33-43.

Parker R. 2013. Field investigation into the impact of task demands on worker responses in the South African forestry silviculture sector. Masters thesis, Rhodes University, South Africa.

Pawson SM, Brin A, Brockerhoff EG, Lamb D, Payn TW, Paquette A, Parrota JA. 2013. Plantation forests, climate change and biodiversity. *Biodiversity Conservation* 22: 1203–1227.

Poyton RJ. 1979. *Tree Planting in Southern Africa. Vol. 2. The eucalypts*. Pretoria: Department of Forestry.

Ramantswana N 2018. Photo: Preparation of a planting position with the MPAT single pitting head machine New Hanover.

Savill P, Evans J, Auclair D, Falck J. 1997. *Plantation Silviculture in Europe*. Oxford University Press. United States New York.

Schönau APG. 1984. Silvicultural considerations for high productivity of Eucalyptus grandis. *Forest Ecology Management* 9: 295–314.

Schönau APG. 1989. Requirements for intensive silviculture. *South African Forestry Journal* 150: 40–49.

Schönau APG, Grey DC.1987. Site requirements of exotic tree species. In von Gadow K, van der Zel DW, van Laar A, Schönau APG, Kassier HW, Warkotsch PW, Vermaas HF, Owne DL, Jordaan JV (eds), *South African Forestry handbook* (2rd edn). Pretoria: South African Institute of Forestry. pp 107 - 108

Schönau APG, Stubbings JA.1987. Silviculture of Eucalypts. In von Gadow K, van der Zel DW, van Laar A, Schönau APG, Kassier HW, Warkotsch PW, Vermaas HF, Owne DL, Jordaan JV (eds), *South African Forestry handbook* (2rd edn). Pretoria: South African Institute of Forestry. pp 107 - 108

Schönau APG, Stubbings JA, Norris C.1993. Silviculture of Eucalypts. In Van der Sijde HA (eds), *South African Forestry handbook* (3rd edn). Pretoria: South African Institute of Forestry Research. pp 171 - 185.

Smith CW. 2000. Site preparation and cultivation at establishment and re-establishment. In: Owen DL (eds), *South African Forestry handbook* (4th edn). Pretoria: South African Institute of Forestry Research. pp 98 – 99.

Smith CW, Norris CH, Esprey LJ. 2000. The effect of land preparation at establishment on the productivity of fast growing hardwoods in South Africa. *ICFR Bulletin Series* 06/2000. Pietermaritzburg: Institute for Commercial Forestry Research.

Smith CW, Little KM, Norris CH. 2001. The effect of site preparation at re-establishment on the productivity of fast growth hardwoods in South Africa. *Australian Forestry* 64: 165-174.

Steenkamp JC. 2008. The effect of HIV and AIDS on the viability and management of forestry contracting businesses in South Africa. DBA, Nelson Mandela Metropolitan University, South Africa.

Steenkamp JC. 2017. Contractors registered with SAFCA. [Email] (Personal communication, 13 March 2018).

Taylor SE, Veal MW, Grift TE, MacDonald TP, Corley FW. 2002. Precision forestry: operational tactics for today and tomorrow. In: Council on Forest Engineering (COFE) *Proceedings of the "Forest Engineering Challenges - A Global Perspective" conference*, June 16-20, Auburn. Council on Forest Engineering.

Theron K. 2000. Establishment. In: Owen DL (eds), *South African Forestry handbook* (4th edn). Pretoria: South African Institute of Forestry Research. pp 97.

University of Pretoria. 2016. Faculty of Natural and Agricultural Sciences: Guide for Research Ethics Research involving human participant. Pretoria: University of Pretoria.

van Wyk A, Brink A, van Huyssteen G, Jansen J (eds). 2006. *Tree Farming Guidelines for Private Growers* (3rd edn). Sappi Forests: Cascades.

Viero P. 2000. Planting. In: Owen DL (eds), *South African Forestry handbook* (4th edn). Pretoria: South African Institute of Forestry Research. vol 1 pp 100 – 101.

Viero P, du Toit B. 2012. Establishment and regeneration of eucalypt, pine and wattle stands. In: Bredenkamp BV, Upfold SJ (eds), *South African Forestry handbook* (5th edn). Pretoria: South African Institute of Forestry Research. pp 99 – 106.

von Benecke. 2015. Toward a new business model for modernised silviculture forestry practices in South Africa: an abductive study. MBA. Cape Town: University of Cape Town

Annexure 1: Re-established areas used to determine proportions for each method categorised per genera

Re-establishment activity	Method	Eucalypt		Pine	
		Method Areas (ha)	Total area (ha)	Method Areas (ha)	Total area (ha)
Residue management	Burning	24 029	29 213	8 564	12 745
	Spreading	1 082	29 213	3 535	12 745
	Mulching	607	29 213	500	12 745
Marking of a planting position	Manual baseline method	16 624	26 362	10 358	10 642
	Using old stump-lines	8 238	26 362	787	10 642
Preparation of a planting position	Manual with road pick	14 422	27 679	7 798	11 163
	Earth auger	1 605	27 679	369	11 163
	Single pitting head machine	6 572	27 679	929	11 163
	Tractor ripping	3 797	27 679	2 000	11 163
Weeding before planting	Manual chemical spray with knapsack	18 582	26 276	8 629	9 724
	Tractor boom spray	5 064	26 276	374	9 724
Planting	Manual hoe / trowel	10 550	25 555	5 920	11 198
	Planting tube	9 947	25 555	4 441	11 198
	Tractor with towed planter	3 558	25 555	704	11 198
Fertilizing	Manual	14 887	25 900	3 153	3 229
Blanking	Manual hoe / trowel	2 931	4 291	2 948	3 305
	Planting tube	1 317	4 291	357	3 305
Weeding after planting	Manual slashing	17 960	93 040	10 849	34 453
	Manual hoeing	16 683	93 040	4 419	34 453
	Chemical spray with knapsack and cones	43 560	93 040	14 912	34 453
	Chemical spray with tractor implements	11 569	93 040	3 145	34 453
	Inter-row tractor disc	1 713	93 040	487	34 453

Annexure 2: Re-established areas used to determine proportions for each method categorised per province

Re-establishment activity	Method	KZN		MP	
		Areas (ha)	Total area (ha)	Areas (ha)	Total area (ha)
Residue management	Burning	15 925	21 136	13599	14 643
	Spreading	1 473	21 136	104	14 643
	Mulching	122	21 136	740	14 643
Marking of a planting position	Manual baseline method	4 049	10 759	13587	14 283
	Using old stump-lines	6 610	10759	696	14 283
Preparation of a planting position	Manual with road pick	5 351	18 647	7 824	14 453
	Earth auger	1 009	18 647	530	14 453
	Single pitting head machine	5 733	18 647	848	14 453
	Tractor ripping	227	18 647	5 250	14 453
Weeding before planting	Manual chemical spray with knapsack	9 695	20 170	7833	9 773
	Tractor boom spray	5 388	20 170	50	9 773
Planting	Manual hoe / trowel	5 684	17 337	5 883	14 113
	Planting tube	6 158	17 337	8 230	14 113
Fertilizing	Manual	6 799	16 304	7 411	8 911
	Fertilizing forks	3 759	16 304	1 170	8 911
Blanking	Manual hoe / trowel	334	1 377	2 424	3 099
	Planting tube	1 000	1 377	674	3 099
Weeding after planting	Manual slashing	13 426	72 819	7 151	38 872
	Manual hoeing	15 720	72 819	3 501	38 872
	Chemical spray with knapsack and cones	26 984	72 819	25438	38 872
	Chemical spray with tractor implements	12 114	72 819	2 600	38 872