Perspectives and drivers of modernisation of silviculture re-establishment in South Africa

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Efficient and cost-effective re-establishment practices are important parts of any sustainable forest re-establishment programme. Re-establishment activities include residue management (post-harvest slash), preparation of a planting position, planting, fertilisation and vegetation management. In South Africa, these activities are largely labour intensive, time-consuming and relatively costly. Although mechanisation of site preparation during afforestation was achieved in the mid to late 1990s, plantation re-establishment operations in South Africa have remained manually oriented. However, there have been notable technology developments over the past decade. Semi-structured interviews were conducted with 66 experts (grower company specialists, foresters, contractors and machine manufacturers) to get their perspectives on modernisation of re-establishment activities in South Africa. Frequency distribution and chi-square test analysis found that two-thirds of the experts believed that re-establishment activities had progressed in terms of technology over the past decade. This development was reported as primarily due to the need to improve health and safety (91%), increase production whilst reducing costs (89%), improve stand productivity (quality) (86%), mitigate social (mainly labour) risks (80%) and reduce prevalent negative environmental impacts (50%). Key barriers to modernisation were identified as the capital cost of equipment (65%), reduction in employment opportunities (44%) and low utilisation of equipment due to seasonality of silviculture work (18%). Experts indicated that the efficiency of mechanised re-establishment equipment can be affected negatively by residues, high stumps and compaction of the site after harvesting. The results of this study will assist forestry stakeholders to make informed decisions when planning and implementing modernised silviculture operations.

Keywords: experts, planting, technology

Introduction

In South Africa, forest plantations cover 1 212 383 million ha, of which about half is owned by corporates. Since the 1980s, the total timber production (m^3) has increased by 54% although the total plantation area increased by only 4% (Godsmark and Oberholzer 2019). Production increase can be attributed to the deployment of genetically improved planting stock which has improved yield and reduced crop risk (Denison 2001; Verryn and Snedden 2012) and the shift from softwoods to hardwoods which have a higher mean annual increment (MAI) (Godsmark and Oberholzer 2019).

Tree improvement for increased timber production should be accompanied by appropriate re-establishment practices to support higher productivity. Existing and future technologies present opportunities in re-establishment to optimise growth and improve productivity and yield (Polder et al. 2010). Efficient and cost-effective re-establishment practices are important parts of any sustainable forest re-establishment programme (Zwolinski and Groenewald 2004).

Re-establishment activities include residue management (post-harvest slash), preparation of a planting position, planting, fertilisation and vegetation management (Theron 2000; Viero and du Toit 2012). These activities are largely labour intensive (Silversides 1984), time-consuming and relatively costly (Evans and Turnbull 2004).

Modernisation entails using the most up-to-date techniques and equipment to perform tasks (Soanes 2001). In forestry, the main functions of modern technology in silvicultural operations are precision, better management, increased efficiency, improved quality, consistency and easier decision-making (Hodgson 1979; Ecolink 2002; Kovácsová and Antalová 2010).

In South Africa, apart from modernisation efforts that were focused on site preparation during afforestation in the mid to late 1990s (Poynton 1979; Froehlich 1984) and technology developments over the past decade (McEwan and Steenkamp 2014; Steenkamp 2017), plantation re-establishment operations have been manually oriented. Unlike harvesting modernisation, which has increased since the 1990s (Mathelele 2019), the uptake of technology in re-establishment has been slow (Silversides 1984). This is due to factors such as variable site conditions and requirements, different landowner objectives and disproportionate economies of scale (Barnett and Baker 1991; Puettmann et al. 2015).

Technological progress does not occur naturally. It is initiated and sustained by identifiable and quantifiable driving forces (Twiss 1992). McEwan and Steenkamp (2014) attribute the movement towards silviculture modernisation in South Africa to the need for reducing the high safety risks associated with ergonomically inferior working posture, the decreasing availability of labour following urban migration, the increased social welfare grants provided by government, the low social status of manual work, the increased absenteeism and turnover of labour and the effects of HIV and AIDS. In the South African context, drivers of modernisation and reasons for the lag in technology adoption are neither well understood nor well documented in literature.

The aim of this study was to determine the perceptions of various South African commercial forestry stakeholders (contractors, grower company foresters and machine manufacturers) on: (i) the modernisation status of re-establishment technology in South Africa; (ii) drivers of and barriers to modernisation in re-establishment operations; and (iii) the commonalities and differences between re-establishment and harvesting activities.

Materials and methods

An exploratory research design was deemed the most appropriate to fulfil the aims of the study. Semi-structured interviews were used as the main instrument to gather the data.

Interview guide development

Relevant topic areas and issues related to modernisation during re-establishment were obtained from previous studies on the subject (Viero and du Toit 2012; McEwan and Steenkamp 2014; Baker 2018; Ersson et al. 2018), interaction with researchers/operational managers involved with modernisation nationally and internationally, and from the corresponding author's past experiences. Areas and issues identified as relevant were grouped under four main sections/themes (Table 1), each containing a set of questions (18 in total).

A set of open and closed-ended questions was developed around the four main themes to direct a semi-structured interview guide covering issues related to modernisation of re-establishment in South Africa. The interview guide was piloted amongst forestry colleagues to check content, length, language suitability and potential sources of bias. To understand the relative importance of areas of the current status of modernisation of re-establishment within South Africa, and to gain insight to drivers of and barriers to the move to modernisation, 66 experts were interviewed (all those invited agreed to participate). The interviews were carried out in accordance with all ethical requirements such as consent, risk, privacy, anonymity, confidentiality and autonomy (University of Pretoria 2016).

Due to the technical nature of the study, judgement sampling was used to select experts for the interviews. Judgment sampling is a form of non-probability sampling where experts are selected based on their knowledge of the subject matter (Marshall 1996; Perla and Provost 2012). The researchers identified potential experts who would bring value to the study, based on their expertise in the field of study. The experts had to comply with three general criteria: (i) the expert had to be directly involved in forestry re-establishment operations; (ii) the expert had to have good knowledge and a minimum of three years' experience in re-establishment operations; and (iii) the expert had to be aware of technology needs in both manual and modernised re-establishment operations.

Participants

The selected experts were foresters, technical experts, contractors and machine manufacturers from the various forest growing regions of South Africa (KwaZulu-Natal, Mpumalanga, Western Cape, Eastern Cape and Limpopo). The diversity in the expert group was important to provide further insight as to perceptions between managers and practitioners from different regions in South Africa. During the interviews, conducted face-to-face or via Skype, the experts were encouraged to elaborate on any of their responses. All interviews were recorded for later extraction of required information.

Data analysis

Responses from the 66 experts were manually and deductively coded (exploratory design). The data were further quantified according to pre-existing themes and sub-themes for further statistical analyses using Statistica Version 13.5.17. For all analyses, the significance level was set at $p < 0.05$. The following analytical procedures were performed on the data:

- Frequency distributions of categorical variables (e.g., re-establishment activities)
- Bivariate associations between categorical variables, using Pearson's chi-square test of independence
- Ranking of level of influence of various change drivers on modernisation (improvements in health and safety, increased operational productivity, improved stand productivity, and environmental and social aspects), using Likert-type scale responses
- Meaningful differences between contractors, grower companies and other experts (i.e., machine manufacturers and government experts), using non-parametric techniques.
- Differences between expert categories (i.e., contractors and grower company), using the Mann–Whitney rank test.
- Kruskal–Wallis test for statistically significant differences between groups when more than two treatments were tested (i.e., contractor, grower company and other experts)

Results

The results are structured according to the aims of the study. The results begin by describing the background of the experts and their perceptions on the status of re-establishment modernisation. Thereafter, the findings focus on current and future drivers of and barriers to modernisation. The final section gives the perceptions of the experts on the relationship between silviculture and harvesting operations.

Background

Sixty-six interviews were conducted with various experts from across different forestry sectors, namely: (i) grower companies (n = 43; 65%); (ii) contractors (n = 15; 23%); (iii) machine manufacturers (n = 4; 6%); and (iv) government (n = 4; 6%). The experts were from KwaZulu-Natal (n = 24; 36%), Mpumalanga (n = 28; 42%), Eastern Cape (n = 7; 11%), Western Cape (n = 6; 9%) and Limpopo (n = 1; 2%), which is a fair representation of the area-by-province afforested in South Africa. Male (n = 49; 74%) and female (n = 17; 26%) experts were interviewed, with the average silviculture experience of the experts being 13 years.

Re-establishment and modernisation status

Out of 66 experts, 44 (67%) indicated that re-establishment activities have progressed significantly in terms of technology over the past 10 years. Irrespective of the designation and experience of the experts, there was no statistically significant difference between contractors and grower company respondents' perspectives on re-establishment technology progress in South Africa, $\chi^2(1) = 0.068$, $p = 0.794$. Furthermore, no significant differences were found between experts with less than 10 years and those with greater than 10 years of experience for their perspective on technology progress in re-establishment, $\chi^2(1) = 2.475$, $p = 0.116$. The experts believed that recent introductions of semi-mechanised and mechanised systems into re-establishment operations are evidence that there has been progress. Irrespective of progress, all concurred that modernisation still has the potential to expand. One of the experts said: "I believe technology has progressed from an ergonomics, safety and labour challenges perspective because there has been a shift from bending, carry trays and limited use of sharp tools to more semi-mechanised type operations".

Based on the experts' perceptions of the level of modernisation for various re-establishment practices, fertilising (73%) and weeding after planting (73%) were rated as the least technologically developed, whilst the preparation of a planting position (58%) was rated as the most moderately advanced activity. Most of the experts rated stump management (mulching for compartment access) (17%) as a highly modernised activity in re-establishment (Figure 1).

Table 1: Information requested from respondents surveyed

No.	Main sections/themes	Information required
1	General silviculture	Description of re-establishment practices
2	Change drivers* and barriers	Details of key current and future modernisation change drivers Barriers preventing the uptake of modernisation in South Africa
3	Activity based innovation	Details of most and least advanced re-establishment activities in terms of modernisation. Future areas for advancement in re-establishment technology
4	Silviculture and harvesting	Details of re-establishment technology development relative to that of harvesting technology development

* 'Change driver' is a term used to describe internal or external pressure factors that shape change

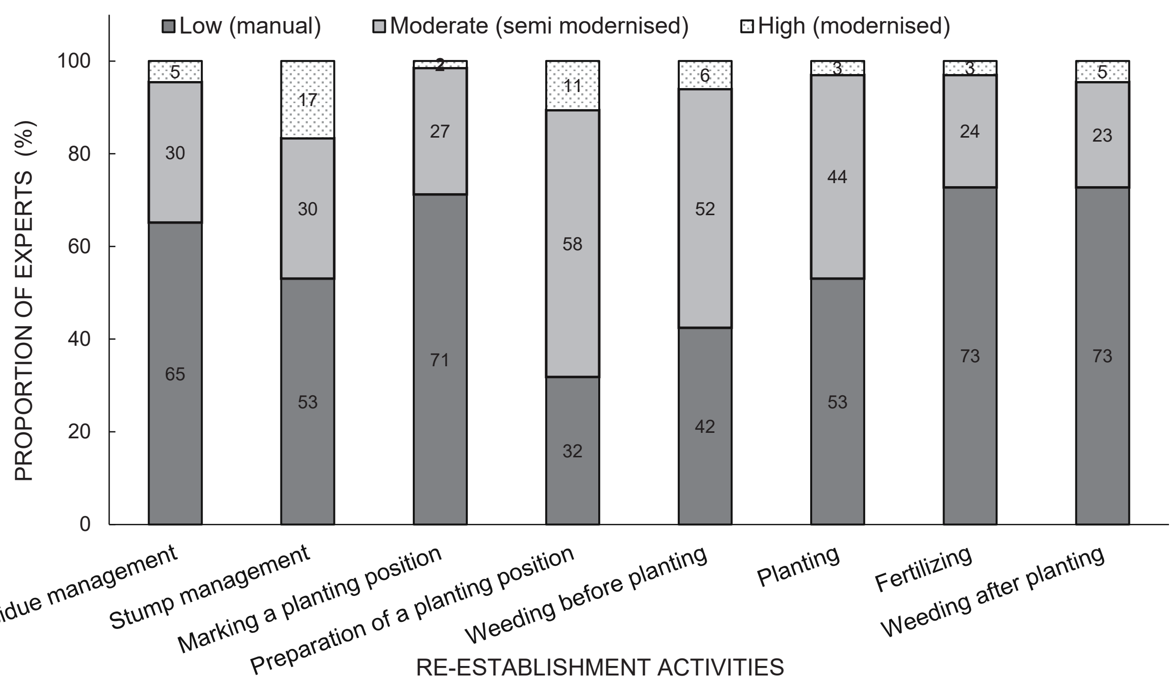

Figure 1: Modernisation ratings for re-establishment activities in South Africa

The perceived levels of modernisation between contractors and grower company were significantly different for planting and weeding where contractors rated both these practices as moderately modernised, whilst grower company experts believed them to be predominantly manual (preparation of a planting position: U = 203.0, z = −2.113, p = 0.034; weeding after planting: U = 168.5, z = −2.726, p = 0.064). In contrast, their perceptions did not differ significantly (p > 0.05) for residue management, stump management, marking for pitting, preparation of a planting position, weeding before planting and fertilising.

The experts specified that, before mechanisation, the most restrictive factors impeding the operational use of machines related to prevailing terrain conditions — such as soil bearing capacity, ground roughness and slope (73%). Other factors such as narrow roads and climatic conditions accounted for 6% of impeding factors (Table 2).

Current and future drivers of modernisation

Most experts identified the need to improve health and safety and to increase productivity whilst simultaneously reducing costs as the two biggest drivers of re-establishment modernisation in commercial forest plantations in South Africa. Improving stand productivity (quality) and reducing social (labour) risks were also identified as important drivers. One half of the experts considered the need to reduce prevalent environmental risks as a driver of modernisation. One-third of the experts mentioned 'other' drivers, including climate change and the need to remain globally competitive (i.e., benchmark productions costs to other countries globally) (Table 3).

To better understand the change drivers, the experts were asked to specify the sub-factors influencing the drive towards modernisation within each category of factors they selected (Table 3).

Based on the degree of importance of each change driver, the experts ranked productivity improvement with cost reduction as a "very important" driver for modernisation of

Table 2: Main factors impeding modernised operations during re-establishment

Impeding factor	Agree, (n = 66) n (%)
Terrain (soil condition, ground roughness and slope)	43 (73%)
Stumps (presence and/or high stumps)	23 (23%)
Harvesting residue	11 (17%)
Inter-row width	5 (5%)
Other (narrow roads and climatic conditions)	4 (6%)

* n is the total number of people who identified a specific impeding factor from the total sample (n = 66)

Table 3: Summary of current drivers of modernisation in re-establishment activities

Change drivers	Agree, (n = 66) n (%)	Sub-factors of change drivers
Improvements in health and safety	60 (91%)	Improvement of ergonomics and reduction of physically demanding work Reduction of exposure to moderate and high risk in operations Reduction of number of incidents and injuries
Increased operational productivity and reduced costs of operation	59 (89%)	Reduction of costs of performing specific activities Improvement of utilisation and efficiency of tools and equipment Improvement of overall output of operations Improvement of consistency of operations
Improved stand productivity (quality)	57 (86%)	Improved survival of plants Improved uniformity of the stand Increased yield
Social aspects/ issues	53 (80%)	Better insulation from negative labour and political impacts Reduced absenteeism and labour turnover Provision of improved quality of work
Environmental aspects/ issues	33 (50%)	Improved conformance to internationally recognised certification standards Reduced impact on soil, water and biodiversity, were applicable Reduced negative public perceptions
Other aspects/ issues	22 (33%)	Climate change: improved adaption to unpredictable weather conductions which influences planting seasons and burning regimes Global competition: need to improve and remain globally relevant in terms of costs and overall efficiency

re-establishment, followed by stand productivity improvement and safety. Social and environment factors were rated as the 'least important drivers' of modernisation (Figure 2). Kruskal–Wallis tests were performed to determine if the various experts (contractor, grower company and other experts) ranked the drivers differently in terms of importance, resulting in no significant differences; they were all $p > 0.05$.

The experts reported that they envisaged the main future (5 to 15 years) change drivers as the need to improve productivity and reduce costs (n = 39; 59%). Other factors identified include social dynamics (mainly related to labour) (n = 29; 44%), safety improvement (n = 25; 38%), quality improvement and consistency (n = 17; 26%) and other factors (availability of technology and climate change) (n = 7; 11%).

Over 60% of the experts forecast that technology progress within the next zero to five years would be in stump management, marking a planting position, preparation of a planting position, pre-plant weeding and planting activities. Most of the experts predicted that technological progress in residue management, fertilisation and weeding after planting would occur after five years (Table 4). When considering re-establishment as a whole, the experts commented that they expected significant advancements to occur in the use of precision technologies (e.g., GPS), integration of specific activities (e.g., pitting and planting), the use of drone technology, automation, robotics, and improved chemical technology.

Just over three-quarters of the experts reported that the forestry industry would adopt purpose-built forestry machines (n = 52; 79%) instead of agricultural equipment adaptations (n = 14; 21%) to carry out re-establishment activities in the future.

The experts identified the main barrier to re-establishment modernisation in South Africa as high cost of capital (n = 43; 65%). Other factors ranked include reduction in employment due to modernisation (n = 29; 44%), low utilisation of equipment due to seasonality of operations (n = 12; 18%), people's mindset in terms of unwillingness to change (n = 11; 17%), and inadequate economies of scale — especially for small landowners (n = 4; 6%).

Silviculture and harvesting compared

Most of the experts (n = 58; 88%) reflected that, when compared to harvesting, re-establishment activities had lagged behind considerably in terms of technological development over the past two decades. The experts commented that most re-establishment activities were still manually oriented, whilst the majority of harvesting activities had become semi-mechanised or fully mechanised. In addition, just over half of the experts (n = 37; 56%) indicated that they thought the change drivers that influenced the movement towards mechanised harvesting are the same as those currently affecting re-establishment modernisation, although the magnitude of influence of

Table 4: Forecast of technology progress in re-establishment activities

Activity	Proportion of total experts (%) (n = 66)	
	0–5 years	>5 years
Residue management	48	52
Stump management	63	38
Marking a planting position	76	24
Preparation of a planting position	90	10
Pre-plant weeding	66	34
Planting	67	33
Fertilising	41	59
Weeding after plant	38	62

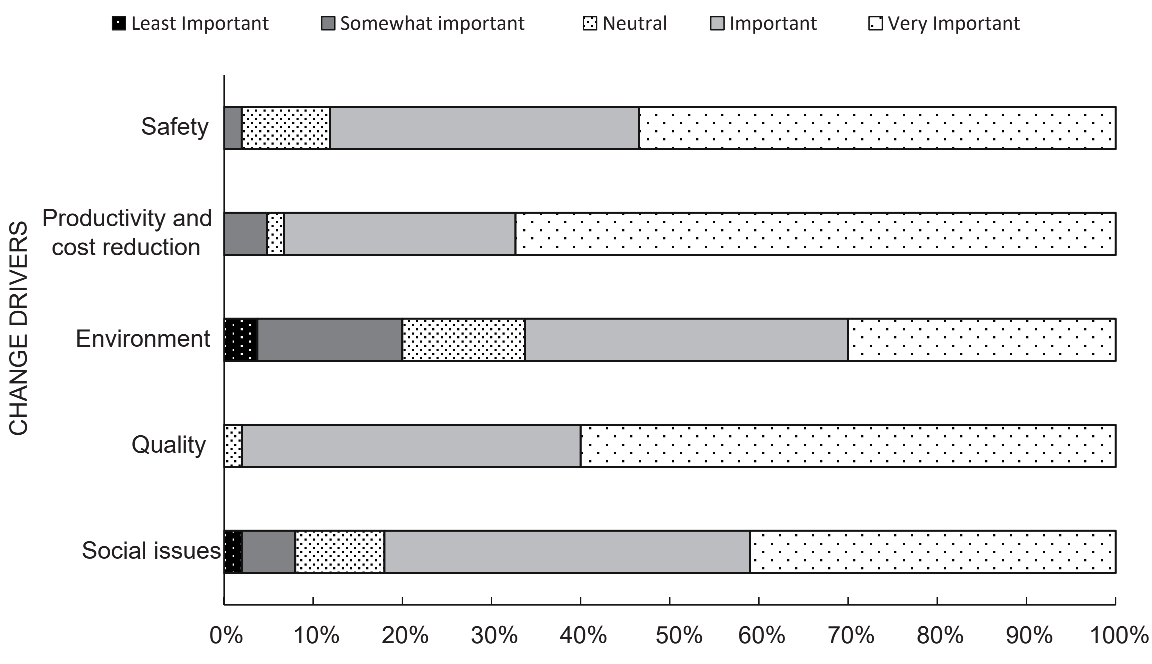

Figure 2: Change drivers ranking from least to very important based on the degree of perceived influence on the rate of modernisation

each change driver differed between the two operations. One of the experts said: "there is definitely overlap between the change drivers between the two operations but in harvesting safety was the number one consideration because of the high risk nature of the work. Silviculture is less risky and progress is mainly driven by the need to increase productivity and reduce costs". In contrast, 35% (*n* = 23) of the experts said they do not think the change drivers are the same and 9% said they do not know.

A high proportion of experts (*n* = 60; 91%) concurred that harvesting method had an influence on the manner in which re-establishment activities were undertaken. Furthermore, experts stated that re-establishment activities were mainly influenced by harvesting residue presentation, stump heights and soil compaction.

Discussion

Re-establishment technology progression

Most experts agree that re-establishment technology has made progress over the past 10 years. According to Steenkamp (2017), the modernisation of silviculture operations in South Africa is imminent and, as technology develops, the manner in which various activities are performed will transform. Even though most re-establishment operations are still manual, new technologies to improve safety and productivity have been introduced in recent years (von Benecke 2015). For example, tree planting has predominantly been manual (trowel and hoe) since the establishment of plantation forests in the mid-1900s (Germishuizen 1982; Viero and du Toit 2012) due to a lack of alternative cost competitive options. However, over the past decade and a half, planting tubes and tractor planters have been introduced to improve ergonomics for workers and increase productivity whilst reducing costs (da Costa 2013).

Physical-environmental barriers to modernisation

Most of the experts agree that terrain (soil condition, ground roughness and slope) and stumps are the greatest physical factors impeding modernised operations during re-establishment. According to McEwan et al. (2013) terrain is the most limiting component for ground-based equipment in forestry applications. Baker (2018) reports that in New Zealand the most significant challenges to mechanising silviculture were steep and variable terrain and dealing with physical impediments. In the Usutu region of eSwatini stumps and rocks were major obstacles preventing the effective mechanical treatment of residues (Germishuizen and Badenhorst 1977; Germishuizen and Marais 1981). Further, slash, stumps and high soil stoniness were identified as important quality and productivity barriers when conducting mechanised mounding and planting in Finland (Saarinen 2006; Timonen et al. 2019). Clearly, terrain is a significant impediment to modernisation in territories beyond South Africa as well.

Socio-economic barriers to modernisation

Regarding socio-economic barriers, South Africa has a high unemployment rate (27.6%) (Statistics South Africa 2019). Therefore, socio-economic barriers — such as the perceived negative impacts of modernisation on employment in rural communities — are important to consider within the South African forestry context. A similar situation is reported for New Zealand, where the introduction of robotics in silviculture activities was perceived as a threat to employment opportunities for people located in rural areas where forestry is practised (Bayne and Parker 2012). When mechanising, it is important to balance the social benefits of manually orientated operations (employment) against the economic benefits of using efficient mechanised alternatives (Chapman and Allan 1978).

Drivers of modernisation

The main driver for modernisation of re-establishment activities is the need to improve workers' ergonomics, which is as important in South Africa as in any other country. For example, Baker (2018) found that in New Zealand the majority of respondents considered the most significant benefit of mechanising silviculture operations was the opportunity to reduce health and safety risks for manual workers. Similarly, in Brazil the priority drivers of mechanising planting operations were the need to improve workers' health (improve ergonomics), increase productivity and reduce silviculture costs (Guerra et al. 2019). In South Africa some large corporations are introducing semi-mechanised and mechanised systems to reduce risks related to performing manual silviculture work (Clarke 2012). Findings from a study conducted in KwaZulu-Natal (South Africa) indicated that semi-mechanised pitting and planting methods are better for the worker than their manual counterparts because of the improved biomechanical (spinal kinematic) responses (Parker 2013).

The second most important driver of modernisation is the need to increase operational productivity and reduce costs of operation. Silviculture work is physically demanding (Boja et al. 2018) and is often accompanied by high seasonal demands for labour (Laine et al. 2016). Mechanisation of silviculture activities reduces the need to employ many people to perform manual tasks (Schönau 1979) because machines offer a higher output per hour or per shift than manual methods. However, the use of machines requires a high initial capital cost, together with regular maintenance (Chapman and Allan 1978).

Although machines may have the same or improved productivity over those of manual operations, the low-cost competitiveness may be a barrier in operations such as planting (Liepiņš et al. 2011; Laine 2017; Ersson et al. 2018). When conducting re-establishment work mechanically, machines have to be able to operate on difficult terrain and large consolidated compartments, and be productive to compensate for the total cost of the machine and operator (Löf et al. 2015). Furthermore, the need to reduce costs and remain competitive is directly linked to the drive to increase productivity. In South Africa, the employment of forestry labour is governed by regulations that set minimum wages, working hours, number of leave days and termination rules. The minimum wage has increased significantly over the last decade. The highest increase was in 2013 when the minimum wage in forestry increased by 56% from ZAR7.32 per hour to

ZAR11.43 per hour (Department of Labour 2018). Because of increased labour costs the modernisation process across harvesting and silviculture was accelerated even though the industry had been gradually mechanising already before 2013 (Chapman 2015).

The experts identified the need to improve stand productivity (quality) as the third most important driver of modernisation. Work quality in re-establishment work is important to ensure survival, growth and uniformity of the stand. The benefit of using a machine to perform re-establishment tasks is that it can consistently attain the required work quality standard throughout the course of the day, unlike manual teams (Hodgson 1979). In south-eastern United States mechanical site preparation improved survival and growth due to improved micro-site conditions after tillage (Veal et al. 2005). Furthermore, when establishing oak stands in Sweden the use of mechanical site preparation by mounding yielded better survival and growth compared to the manual method (Löf et al. 2015). The quality of mechanised planting has been reported to be comparable to manual planting in the Nordic countries (Luoranen et al. 2011; Ersson 2014) because it is able to plant seedlings deeper and more consistently than manual planting (Laine 2017). However, in South Africa, several studies (Light 2015; Dovey 2016; Hechter 2019) have found no significant differences between manual (pick) and motor manual (auger) pitting on tree performance.

The experts identified social aspects such as insulation from negative labour impacts (e.g., dealing with unionised labour) and the high labour turnover as a driver for the modernisation of re-establishment activities. In South Africa, the social drivers of modernisation are mainly labour related. Drivers that were reported in the literature include high labour turnover and the lack of available and willing labour (Steenkamp 2007), and the migration of people from rural to urban areas for better work opportunities (McEwan and Steenkamp 2014; Ntshidi 2017; Mlambo 2018). Forest labourers receive low wages, lack benefits and severance pay and endure long working hours (Clarke 2012), which makes the job unattractive, especially for younger workers. In turn, actual or prospective labour shortages may encourage the modernisation of re-establishment activities. In other countries, such as Finland and Sweden, mechanised planting was introduced to alleviate labour shortages (Ersson et al. 2018).

The experts reported two main environmental drivers of modernisation in South Africa. Some experts believe that, due to increased pressure by certification bodies and greater public concern to reduce chemical usage, more mechanised weeding equipment — such as tractor-drawn slashers (for vegetation management) and precision chemical spraying equipment — will be used to efficiently manage weeds. Although mechanisation may occur as a result of this factor, it is important that an integrated forest vegetation management approach which contemplates various treatments and their effectiveness whilst responding to public concerns is considered (Little et al. 2006).

Another environmental motivation for modernisation provided by experts was the effect of climate change. Experts indicated that due to changing climatic conditions, such as the prevalence of droughts and reduced planting windows, productive operations will need to be completed within the optimal period, which manual teams may not be able to achieve. Climate change has been identified as a challenge to traditional silviculture operations because it may affect site factors, patterns of precipitation, frequency of severe storms, droughts, fires and pests (Hedden 1988; Fearnside 1998; Mason 2007; Brang et al. 2008). The direct effects of climate change on modernisation in silviculture have not been researched. However, foresters need to be aware of the nature and implications of climate change in order to develop management strategies that may mitigate its negative effects whilst ensuring sustainability of plantation forests (Skinner 2007).

Relationship between silviculture and harvesting

Re-establishment, tending and harvesting are interdependent within the overall silvicultural system (Nyland 2002). The experts in our study indicated that harvesting influenced the choice of silviculture operations, mainly due to the influence on residues, stump height and soil compaction. Depending on whether the harvesting system is semi-mechanised or mechanised, the spreading of harvesting residues can differ. If residues are broadcasted, the quality of soil preparation and planting operations can be reduced (Gonçalves et al. 2008). Germishuizen and Badenhorst (1977) found that harvesting systems (skidders, draught animals and highlead winching) in Usutu presented problems for site preparation because of the distribution of slash. Rolando and Little (2006) found that harvesting residues were a hindrance to manual pit preparation and planting activities. However, residues can be important in reducing compaction and erosion when mechanised systems are used on a site (Hutchings et al. 2002).

Conclusions

Over the past decade, South Africa has undergone a process of modernising re-establishment activities. This study showed that different stakeholders within the forestry industry believe that re-establishment activities have progressed in terms of technology, mainly driven by the need to improve health and safety, increase productivity, control costs, improve work quality, mitigate social risks and reduce prevalent environmental impacts. Progress has been slowed down by barriers such as impeding site factors (terrain, stumps, harvest residues and interrow width), high capital cost of equipment, reduction in employment opportunities, low utilisation of equipment due to seasonality of operations and unwillingness to change. In particular, slash, tall stumps and soil compaction caused by harvesting operations are hindrances to the effective application of mechanised re-establishment equipment on a site.

This study provides a holistic understanding of re-establishment modernisation drivers and barriers in South Africa, as perceived by foresters, technical experts, contractors and machine manufacturers. It is important to note some limitations of the study such as expert bias. Furthermore, it is also likely that other researchers may have attributed some answers to categories different from those in this study. Future studies may benefit from investigating the perspectives of other experts, labour and local communities.

The main drivers of and barriers to modernisation need to be monitored so that forestry stakeholders can be made aware of the risks and opportunities involved in modernising re-establishment activities.

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