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ORIGINAL RESEARCH

Ranking Research and Development Needs of Silvicultural Operations for a Plantation Forestry Cooperative

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Abstract

Forest Owners Organizations can help small- and medium-scale private landowners stay competitive by conducting and sharing research and development (R&D) activities. This study evaluated R&D needs for silvicultural operations to inform an R&D strategy for the cooperative. Individual and group priorities were collected using the Analytical Hierarchy Process via a web survey and web meeting. Consensus in priorities was followed by an assessment of the cooperative's capacity to carry out in-house research. Two regional managers, eight plantation managers and one R&D/Technology manager participated in one or more stages of the process. Participants ranked most silvicultural operations similarly. However, the variation was largest for harvest residue, seedling, and stump management. Minor regional differences were found but both regions (south and north) had "very high" group consensus indicators (86.2% and 89%, respectively). The group decision ranked R&D in harvest residue management as the highest priority, followed by soil preparation and planting methods. The cooperative's strongest capacity for in-house research was in the execution of the experimental design to address the research questions (implementation). The weakest research capacity was found in terms of harvest residue, seedling, and stump management. Hence, the cooperative is dependent on research institutions. These findings can be used to inform and align the cooperative's R&D strategy, investments, and their research collaborations.

Keywords Analytical hierarchy process (AHP) · Decision-making · Appropriate technology · R&D strategy · Cooperatives

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Introduction

Cooperatives play a significant role in the success of small- and medium-scale timber growers by: providing access to local and international markets; innovative research and knowledge dissemination; reducing members' transaction costs; increasing geographic coherence of forestry interventions; and promoting market competitiveness through continuous support in forest technology, and sustainable management practices through certification schemes (Ota 2006; Upfold et al. 2015; Weiss et al. 2012). Weiss et al. (2012) describe Forest Owners Organizations (FOOs) as cooperatives (local) and associations (national) whose members are individuals, groups, or communities. The composition of the FOOs can be through corporate out-grower schemes, partnerships, or community-owned private or commercial timber cooperatives (Upfold et al. 2015). FOOs by their constitution are required to seek broader consensus in decision-making and be able to quantify and deal with the consequences of compromises when it comes to investments and operations.

Decision-making in research and development (R&D) is a critical component of any organization aiming to remain competitive and relevant in an ever-evolving global economy. Therefore, decision-making requires the consideration of multiple criteria that can support corporate strategy while prioritizing relevant needs and considering available capacities to meet R&D priorities. R&D for cooperatives can be understood in the context of both academic/institutional and industrial R&D. Academic/institutional R&D aims to obtain new knowledge which can yield useful information to be applied to practical uses (Moris 2018). Whereas industrial R&D aims to obtain new knowledge that is applicable to the company's business needs, which eventually result in new or improved products, processes, systems or services that can increase the company's added value (Moris 2018). The nature of forestry research requires both contexts for it to be relevant.

One of the major challenges facing cooperatives and other member-based organizations is understanding and adapting to the changing needs of current and prospective members as structural changes take place within the broader societal environment (Kronholm 2016). The changes are due to varying reasons such as diversification, urbanization, economic restructuring, declining economic dependence on forestry (Andersson and Keskitalo 2019) and the ageing population of forest owners in some parts of the world, such as Sweden (Kronholm 2016). It can also come about as a shift associated with new and inexperienced owners of diverse age groups reclaiming or being awarded forest land of which they have been previously dispossessed (Upfold et al. 2015).

Larger corporations (shareholder-based) and forestry cooperatives (offering membership to small- and medium-scale private timber growers) face similar challenges, but the severity of the challenges is exacerbated by the diseconomies of scale when it comes to the size of the land holdings, supply chain efficiencies, funding capacities (Upfold et al. 2015), and access to local and international markets (Clarke 2018).

Factors such as income from the forest, certification, interest, and knowledge in forest management issues have a large influence on the management strategies chosen by small-scale private forest owners (Eggers et al. 2014). Certification schemes, in particular, guide forest managers to work towards criteria and indicators that align with market-based certification systems such as the PEFC (Programme for the Endorsement of Forest Certification) and the FSC (Forest Stewardship Council) (Pynnönen 2020). As shown in the work by Lidestav and Lejon (2011) certification schemes influenced management practices resulting in more frequent harvesting and silvicultural activity compared to non-certified management units. Although the debate continues on the effectiveness, validity and benefits of certification schemes, especially for small-scale timber growers, they do improve their attractiveness in the market since some timber buyers and product consumers prefer to buy from certified forests (Rametsteiner and Simula 2003; Ota 2006; Yao et al. 2021). Thus, the R&D strategy must be balanced in providing guidance on the direction in which cooperatives can maximize their innovative capacity relating to technologies, services and products that better suit the needs of their members and explore new opportunities to ensure income and means of developing the business while remaining competitive (Jelinek et al. 2015; Young et al. 2020).

In a cooperative setting, the complexity of the decision-making process does not necessarily depend on a single person or office but is the product of consolidating input from multiple stakeholders while acknowledging the variability in the underlying operational framework (Reynolds 1997). In facilitating this process of consolidation, appropriate tools should be implemented to support decision-making by considering the multiple criteria and input specified by stakeholders and making these explicit to all concerned. The relationship between forest owners and the associations will become more focused on individuals' needs and benefits rather than the collective interest of owners as a group (Kronholm 2016). Therefore, research investments should be tailored to serve the needs of the cooperatives and their members considering the context in which small-and medium-scale timber growers operate, to provide appropriate technologies for their competitiveness in the industry.

Multi-criteria decision-making methods (MCDMs) have been developed to support decision-makers in reaching consensus in solving a problem with multiple, and potentially conflicting, alternatives (Khan et al. 2020) Forestry decision-making typically involves objectives related to environmental/ecological, economic, and social issues at the same time (Kangas and Kangas 2004). In addition, decisions can be considered from a strategic, tactical, and operational perspective and may vary depending on the organizational goals (Blagojević et al. 2019). A variety of MCDMs have been applied in forestry to support decision-making relating to sustainable forest management (Diaz-Balteiro and Romero 2008; Kangas and Kangas 2005; Valls-Donderis et al. 2017) road management/planning (Buğday and Akay 2019; Çalişkan 2017; Faramarzi et al. 2021; Gumus 2017), assessing fire risks (Da Silveira et al. 2008; Kayet et al. 2020; Sari 2021), strategies for smallholder farmers (Stainback et al. 2012; Thomas et al. 2021; Zhang and Paudel 2021), machine selection (Perez-Rodriguez and Rojo-Alboreca 2012; Talbot et al. 2014) and the development of models to assist in decision-making regarding forest operations (Ramantswana et al. 2020a, b, c; Rönnqvist et al. 2015).

Using a specific MCDM tool may not always meet the objectives of the constraints of the problem. To compensate for some of the shortcomings, researchers combine different MCDM tools which further increases and improves the information base for strategic processes (Kajanus et al. 2012). The hybridization of MCDM tools has become prominent in group decision-making (GDM), with the Analytical Hierarchy Process (AHP) being the most frequently used together with other MCDMs (Ortiz-Urbina et al. 2019).

The AHP method developed in the 1970s provides a simple approach to deriving ratio scales reflecting the relative strength of preferences from discrete and continuous pairwise comparisons addressing multicriteria planning and resource allocation problems (Saaty 1977). The decomposition of the problem into a hierarchical structure helps to improve the uncertainties of the general problem by further decomposing it into sub-criteria (Saaty 1977, 2008). Depending on the tool used, preferences can be represented by ordinal information (usually expressed in a ranking of alternatives) or cardinal information (value, utility function or priority values) (Ortiz-Urbina et al. 2019). For example, in the study by Rietz et al. (2015), stakeholders were asked to use an ordinal ranking of research priorities based on a high, medium or low scale of importance, while a typical AHP study would implement cardinal priority ranking to indicate intensity in priorities by the ratios of numerical values (Saaty 1977, 1994).

Group decision-making (GDM) could be considered more necessary in a cooperative setting than elsewhere. Forestry Associations' decision-making is a rather challenging procedure since the scope comes at a cost for the association's span of activities as timber production is reliant on its members (Blagojevic et al. 2020; Górriz-Mifsud et al. 2019). Górriz-Mifsud et al. (2019) suggest that even though group members lose some decisional power over their own forest holdings, group decision-making is critical for associations.

An R&D strategy involves generating new overarching perspectives for re-evaluating existing business approaches (Jelinek et al. 2015). The strategy can be driven by external factors such as environmental sustainability underlining tension between short and long term, profit, and future strategic needs (Jelinek et al. 2015). In the context of this paper, the R&D strategy is driven by the cooperative's strategy, which in part aims to ensure the appropriateness of technology (NCT 2022b). Appropriate technologies (AT) and methods in silvicultural operations are of special interest in this paper and can be understood in the context of developing countries, especially small-and medium-scale private timber growers as per definition by Grobbelaar, (2000) "AT is a spectrum of basic, intermediate and highly mechanized technology that is evaluated for a specific situation along agreed-upon social, environmental and economic criteria, supporting sustainable development." Investing in R&D helps in the production of cutting-edge knowledge with high-level human resources and skills that enhance the possibility of deploying AT in the industry.

The progression of forest operations technology has largely focused on improving mechanical performance, productivity, and the development of work methods through improved technology (Brown et al. 2020). The application of MCDMs aided these advancements by allowing decision-making that considers factors that influence machine selection and the development of new technologies (Blagojević et al. 2019; Brown et al. 2020). Although the technological advances are recognized for their need in enhancing operational efficiency, conditions in developing and developed countries require different approaches to technologies for the specific socio-economic, forestry landscape and ownership conditions, to name a few.

Silvicultural operations refer to activities concerning site preparation, establishment and/or regeneration, and tending of plantation forests. These activities are influenced by the plantation management system, and in the context of South Africa, an even-aged system (Du Toit and Norris 2012). The adoption of technological advancements in South African silvicultural operations, specifically in re-establishment (e.g., practices such as site preparation including, but not limited to burning or broadcasting of harvest residue) is projected to increase by 50% in the near future (Ramantswana et al. 2019). Advances in machine technology have enabled multi-functional capabilities, improved handling, and the use of drones. With progression from manual tools like picks, hoes, and augers have been strengthened with motor-power, semi-mechanization and full mechanization of some re-establishment. (Ramantswana et al. 2020a, b, c).

Forestry cooperatives in South Africa do not anticipate their operations to be fully mechanized in the near future (Rietz et al. 2015). Silvicultural operations are an area where the greatest opportunities for improved operational efficiencies exist, even if not being fully mechanized (Rietz et al. 2015). Considering that silviculture operations are still predominantly manual or motor-manual, the identification of research priorities for small-scale and manual interventions should not be neglected. However, deciding which operations to prioritize requires structural and interactive methods that can incorporate relevant research needs from multiple stakeholders' perspectives (Rönnqvist et al. 2015).

The study therefore aims to identify R&D priority needs in silvicultural operations of a plantation forestry cooperative based in South Africa, using the AHP method to inform R&D strategy formulation based on individual and group decision-making. Additionally, we evaluate a cooperative's capacity to conduct in-house research for the identified priorities.

Methodology

Study Location and Recruitment of Participants

The study was conducted on a large forestry cooperative operating in commercial plantation forestry in South Africa, NCT Forestry Agricultural Cooperative Limited (NCT). The cooperative plays a key role in supporting and representing approximately 1600 members who are private, independent timber growers. The members' timber resource covers 21% (311 563 ha) of the country's afforested land, where NCT's owned and leased land, account for 19 000 ha (NCT 2022b). Approximately 2 million tons of timber per annum are sold to local and international markets with most being from its members, while the NCT-owned tree farms serve as reserves. The cooperative offers services to its members and provides management services for its timber plantations and landowners (NCT, 2022a).

Services offered to members include timber plantation management, marketing, logistics (transportation of timber), harvesting, silviculture, technology transfer, tree improvement and mapping (NCT 2023). The focus of the study is on the Tree Farming division and technology transfer services which includes R&D. The Tree Farming division includes the management of NCT-owned timber plantations and those of its members requiring a management service. The majority of the services and timber plantations are situated in Kwa-Zulu Natal province, and, to a lesser extent, in the Eastern Cape, Mpumalanga, Limpopo and Swaziland (NCT 2023).

The recruitment and sampling process for this study was conducted through convenience sampling after the cooperative's senior management's (R&D and Tree Farming Technology (RDT)) consent for the study to be conducted. Ten plantation managers, five from each region (north and south), two regional managers (one from each region) and the R&D and TFT manager representing the cooperative's R&D division were recruited (Fig. 1). The participants were recruited because of their influential role in the cooperative, relating to tree farming, technology, R&D and silvicultural work. A plantation manager is responsible for the planning, supervision, and implementation of forest management activities, including harvesting, silviculture, road maintenance, logistics, contractual relationships, conservation management, financial management and the legal implications of managing a timber plantation. A timber plantation is typically 3000–5000 ha, consisting of management units (compartments) of 10-30 ha, where the work is carried out by both an in-house workforce and external contractors. Regional/senior managers are responsible for the strategic and operational decision-making and oversight of the timber plantations in their respective regions and enjoy a large degree of autonomy. The RDT manager plays a crucial role in R&D within all aspects of forest management, while ensuring compliance with certification schemes.

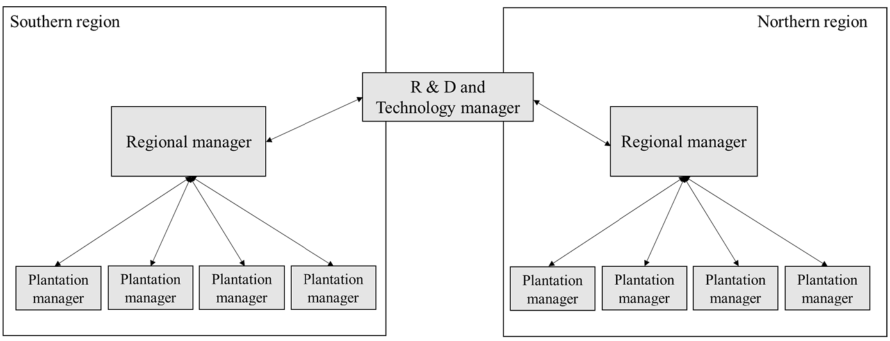


Fig. 1 The structure of managerial roles related to the R&D decision-making within the cooperative

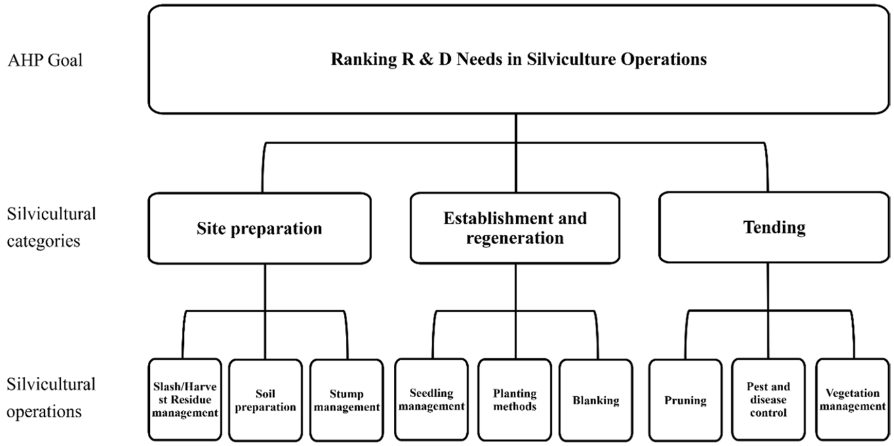


Fig. 2 AHP hierarchy for the R&D needs in silviculture operations. Categorization of silvicultural operations was based on the work of various authors (Du Toit and Norris 2012; Viero and Du Toit 2012; Ramantswana et al. 2020a, b, c)

Analytical Hierarchy Process

Part 1: Questionnaire Development

The AHP-process included three sequential surveys, with questionnaires (Survey 1 and 2) and a questionnaire-based interview (Survey 3). For survey 1 and 2, the first step was to construct a hierarchy (Fig. 2) that structured the goal of the AHP into a sequence of criteria which could be compared and ranked. This was done by breaking down silviculture R&D needs into categories and operations (attributes) using literature for plantation-based silviculture (Du Toit and Norris 2012; Viero and Du Toit 2012; Ramantswana et al. 2020a, b, c). All attributes (Table 1) were described to participants to ensure that they had a common understanding of what was meant by R&D in each operation for all three surveys.

A multiple-choice electronic questionnaire was formulated in Microsoft Forms following the development of the AHP hierarchy for Survey 1 and 2. The participants were to conduct pairwise comparisons between the attributes by choosing between different responses (Table 2). To ensure the questionnaire's usability, estimated duration, and clarity (including the hierarchy and description of attributes), a pilot study was conducted with four forestry academics and two silviculture practitioners who were not recruited for this study. The usability and clarity of the study was verified with feedback to include a progress bar to the questionnaire and a short break (an image saying "take a break") was recommended on a slide halfway through the questionnaire to reduce potential survey fatigue.

Lastly, a separate questionnaire (Survey 3) was constructed to evaluate the in-house R&D capacity based on eight indicators (Table 3). This included an option performance matrix (part of AHP) using pairwise comparison of each capacity indicator. Table 2 was amended to fit a ranking scale for "strength of capacity"

Table 1 Description of R&D research examples that make up each silvicultural operation for which respondents were to consider when ranking R&D needs

Harvest residue management (HRM):	Methods for chipping, crushing, or mulching the material, investigating productivity and costs, methods of assessing the quality of work, the efficiency of windrowing or burning and the material's effects on replanting, including avoiding delays with burning time-windows, or of windrowing vs spreading on accessibility
Soil preparation (SP)	Cost and effectiveness of various machines and equipment, including manual pitting tools, to find robust solutions that allow for good early growth and survival of seedlings. Includes pitting, ploughing, ripping, etc
Stump management (Stump M.)	Developing drone-based methods for assessing stump heights, finding efficient work patterns for partial or total mulching and grinding, or in the case of eucalyptus, managing stumps for coppice
Seedling management (Seed.M)	From nursery, to transportation to the planting site and maintaining the quality of seedlings. Tracking seedlings from the nursery through transport and holding before planting, investigating practices that can enhance or are detrimental to seedling vitality, investigating seedling carrying, handling equipment and methods for which more effective solutions can be found
Planting methods (PM)	Examining current work systems and equipment/machinery used in comparison to other systems on the market, in terms of efficiency, survival, and quality of root network development
Blanking	Finding better methods (e.g., drone-based) for assessing whether a blanking is needed and how many seedlings to plant, when it should take place, what the longer-term economic returns are, and methods for site preparation concerning blanking
Pruning	The cost-effectiveness of manual vs. motor-manual pruning in different conditions, benefits from improved saw maintenance, finding good task levels based on branchiness and pruning height, ergonomics, and safety aspects
Pest and disease control (PDC)	Preventative practices such as manual, motorized, mechanized and drone-based spraying equipment, assessment of areas in need of treatment using drone-based imagery, and development of decision trees on when to apply which technology
Vegetation management (Veg. M)	Current methods including chemical and mechanical alternatives and whether these could be applied more effectively. New technologies and assessment methods (e.g., drone-based) for more targeted application of treatment resources, and development of methods to assess the effectiveness of such methods

Attributes were derived from literature relating to silviculture activities practiced in plantation forestry (Du Toit and Norris 2012; Ramantswana et al. 2019; Ramantswana et al. 2021; Rietz et al. 2015; Upfold et al. 2015)

in each indicator, where 'more' is replaced with 'strong/stronger' and 'less' with 'weak/weaker'. For example, the response option for the pairwise comparison when evaluating the cooperative's capacity to conduct in-house R & D in soil preparation could be: "…moderately stronger capacity in indicator A compared to

Table 2 Scale of importance (adapted from Saaty 1977) and the corresponding multiple-choice questionnaire responses for each pairwise comparison

Interpretation	Intensity of importance and their reciprocals	Questionnaire response options E.g., in my opinion R&D in attribute A is…
Equal importance	1	…equally important as R&D in attribute B
Moderate importance	3	…moderately more important than R&D in attribute B
	1/3	…moderately less important than R&D in attribute B
Strong importance	5	…strongly more important than R&D in attribute B
	1/5	…strongly less important than R&D in attribute B
Very strong importance	7	… very strongly more important than R&D in attribute B
	1/7	… very strongly less important than R&D in attribute B
Extreme importance	9	…extremely more important than R&D in attribute B
	1/9	…extremely less important than R&D in attribute B
Intermediate values between two adjacent judgments	2,4,6,8 1/2,1/4,1/6,1/8	When compromise is needed

Table 3 Indicators for the evaluation of in-house research capacity for the cooperative based on relevance to the cooperative and silviculture operations extracted from the literature (Cooke 2005; Jelinek et al. 2015; Pulford et al. 2020)

Capacity indicator	Explanation
Experimental design	The ability to design experiments that are appropriate to have the desired outcome for the research question
Equipment devices/ tools	The various tools and equipment required to conduct the research and experiments based on the experimental design
Implementation	Execution of the experimental design with the intended activities to address the question
Data collection	The process of gathering and measuring information on variables of interest based on the research in question
Data analysis	The process of cleaning, processing, modelling and transforming data to conclude using basic statistics, or more advanced statistical analyses based on experimental design
Interpretation	Interpretation of the results from research conducted and its implementation to inform decision-making and interventions based on what the results mean in relation to the research question
Analysis of information from different sources	Investigation and evaluation of various sources related to the research question of interest to support further interpretation of the findings
Report writing	A logical presentation of facts and information serving a specific purpose related to the research investigated, the processes implemented, a summary of the findings and the recommendations relating to the problem

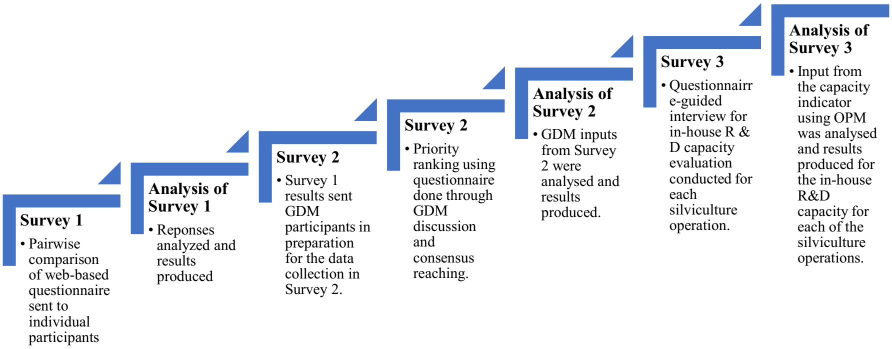


Fig. 3 Data collection and analysis process followed during implementation of the AHP method

indicator B" or "…moderately weaker capacity in indicator A compared to indicator B."

Part 2: Data Collection and Analysis

Figure 3 demonstrates the overall data collection process followed as part of implementing the AHP method. In Survey 1, the individual priority rankings for silvicultural R&D needs of eight plantation and two regional managers were collected through the web-based questionnaire. The results from Survey 1 were disseminated to two regional managers and the RDT manager to familiarize themselves with the individual priority rankings before data collection in Survey 2. This was done to ensure the plantation manager's interests were considered when engaging in the group-decision making (GDM) process. A week later, the GDM process was facilitated during a live questionnaire-based discussion on MS Teams. The data (priority value) were captured in the AHP-Excel tool (Goepel 2013) for each pairwise comparison once a consensus was reached between the three participants during the discussion. In Survey 3, the RDT manager, as the most senior in the cooperative's R&D management and involved with silvicultural operations, participated in a questionnaire-guided interview to evaluate the cooperative's capacity to do in-house research for each of the silvicultural operations. Prior and during the interview, the manager had access to the indicators for general research considered in the evaluation (Table 3) and access to the proposed R&D in each operation (Table 2), but only heard the questions during the interview. Data was recorded on a pre-designed capacity indicator pairwise comparison Excel template for each silvicultural operation using the amended "scale of capacity" as previously explained.

Data Analysis

Upon receipt of the data from the completed questionnaire in Survey 1, each input was converted to the numerical equivalent of the response chosen in the multiple-choice (Table 2). For example, if the answer to the pairwise comparison in question

1 was chosen as "…A is moderately less important than R&D in attribute B" the numerical equivalent will be 1/3 as shown in Table 2. Thereafter, the response of each individual was recorded in a separate sheet of the AHP Excel template by Goepel, (2013). The template allows for up to 10 individual inputs. Once all the relevant data was inserted and the judgment scale defined, the template automatically calculates and generates individual priorities using the geometric row mean method, final priorities using the eigenvector method, and consistency ratios for each individual input. A 9×9 matrix with 36 $(n(n-1)/2)$ paired attributes, where $n = 9$ was also generated. Furthermore, a group consensus indicator was generated for each region based on aggregated individual judgments. The same template was used in survey 2, however, however, the data was recorded in the AHP Excel template during the interview. This study did not focus on the mathematics of the calculations, but rather on the implementation of the well-documented AHP methods. A more detailed explanation and understanding of the equations applied in the design of the AHP Excel template is provided by Goepel, (2013) and Goepel (2018).

In survey 3, the data recorded in Excel during the interview was inserted into the AHP Excel template, and an option performance matrix was produced for each silviculture operation as shown in Table 4. For operations where the RDT manager evaluated research indicators as having "no capacity", the value 1 (equal capacity) was assigned. On each of the silvicultural operations (attributes), the sum product of the GDM priority rankings, and research capacity rankings was calculated to determine which prioritized operations the cooperative had the strongest capacity to do in-house research for.

Results

The ranked priorities of the R&D needs identified by the plantation managers (F1–F8) and their respective regional managers (M2 and M3) varied between individuals (Table 5). Although F1, F2 and M3, showed similarities in some rankings, they showed significantly opposing priorities for R&D needs in harvest residue, seedling, and stump management (Table 5).

Plantation managers (F1–F4) and regional managers (M2) in the southern region were quite unanimous in the low ranking of pests and disease control (PDC), planting methods (PM), and vegetation management (Veg. M) and the mid ranking of blanking and pruning (Table 5). However, there was some dispersion between the more highly ranked harvest residue management (HRM), seedling management (Seed. M), soil preparation (Soil P.) and stump management (Stump M.). For example, F1 assigned the highest priority ranking for Stump M. whereas F2 ranked it the lowest priority. Interestingly, all participants assigned a high priority ranking for HRM, except M2 who ranked it the third lowest priority. Moreover, Seed. M received quite a bit lower priority by F1, while all other respondents ranked Seed. M among their top three priorities. F1 was also more negative about prioritizing Soil preparation (SP) compared to the other respondents (Table 5).

The northern region's judgments appear to follow similar order in their rankings for prioritizing R&D for silvicultural operations. Participants had mid-to-low

Table 4 Option performance matrix for capacity indicators for R&D in soil preparation

Soil Preparation	Experimental design	Equipment devices/ tools	Implementation	Data collection	Data analysis	Interpretation	Analysis of information from different sources	Report writing	Normalized principal Eigenvector (%)
Experimental design	1	1/2	2	1	1	4	6	6	15.95
Equipment devices/ tools	2	1	6	1	1	4	4	4	26.45
Implementation	1/2	1/6	1	8	8	2	6	6	23.96
Data collection	1	1	1/8	1	8	2	2	6	13.77
Data analysis	1	1	1/8	1/8	1	1/3	1/2	1	5.73
Interpretation	1/4	1/4	1/2	1/8	3	1	4	4	7.74
Analysis of information from different sources	1/6	1/4	1/6	1/2	2	1/4	1	2	4.09
Report writing	1/6	1/4	1/6	1/6	1	1/4	1/2	1	2.66

A higher Eigenvector indicates more capacity and a lower value represents less capacity. Each operation had its own matrix with the same research capacity indicators

Table 5 Individual priority judgments from survey 1 (web-based questionnaire) for each silviculture operation in order of lowest to highest rankings

Southern Region

Operations (Ops)	M2	Ops	F1	Ops	F2	Ops	F3	Ops	F4
Vegetation management (Veg. M)	0.04	Veg. M	0.04	Stump M	0.05	PDC	0.06	Veg. M	0.07
Pest and disease control (PDC)	0.05	PM	0.07	Blanking	0.07	Stump M	0.08	PDC	0.08
Harvest residue management (HRM)	0.09	Pruning	0.08	PDC	0.07	PM	0.09	PM	0.09
Planting methods (PM)	0.11	SP	0.08	Pruning	0.07	Veg. M	0.09	Pruning	0.09
Pruning	0.11	Seed. M	0.09	PM	0.08	Blanking	0.11	Blanking	0.10
Blanking	0.12	Blanking	0.14	Veg. M	0.10	SP	0.13	SP	0.10
Stump management (Stump M.)	0.14	PDC	0.14	Seed. M	0.16	Pruning	0.14	Stump M	0.10
Soil preparation (SP)	0.15	HRM	0.18	SP	0.16	Seed. M	0.14	HRM	0.14
Seedling management (Seed.M)	0.19	Stump M	0.18	HRM	0.24	HRM	0.15	Seed. M	0.22

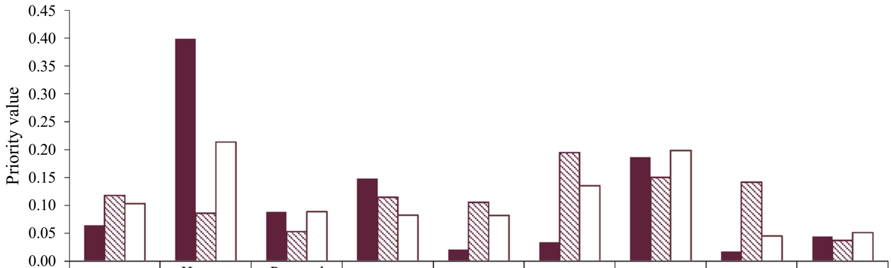
Northern region

Operations	M3	Ops	F5	Ops	F6	Ops	F7	Ops	F8
Stump management (Stump M.)	0.05	Veg. M	0.03	Stump M	0.06	Veg. M	0.03	Stump M	0.04
Vegetation management (Veg. M)	0.05	Blanking	0.04	Veg. M	0.07	Stump M	0.07	Veg. M	0.07
Planting methods (PM)	0.08	Pruning	0.06	PDC	0.08	HRM	0.09	Blanking	0.08
Pruning	0.08	PDC	0.07	Blanking	0.10	PDC	0.10	PDC	0.09
Pest and disease control (PDC)	0.09	PM	0.08	PM	0.11	PM	0.11	PM	0.10
Blanking	0.10	Seed. M	0.08	Pruning	0.11	Pruning	0.11	Pruning	0.10
Seedling management (Seed.M)	0.14	SP	0.14	HRM	0.14	Blanking	0.14	HRM	0.14
Soil preparation (SP)	0.20	Stump M	0.24	SP	0.14	SP	0.14	SP	0.19
Harvest residue management (HRM)	0.21	HRM	0.26	Seed. M	0.19	Seed. M	0.21	Seed. M	0.20

Higher numbers indicate higher priorities

priority rankings for blanking, PDC PM pruning, Stump. M (all but F5) and Veg. M, Seed. M, HRM and SP were ranked highly by all. F5 stands out in the high ranking of Stump.M, which generally was ranked the lowest priority. Participants F6–8 assigned the highest priority to Seed M., and M3 and F5 assigned it to HRM (Table 5).

The southern region's individual consistency ratios (CR) ranged from 0.17 to 0.52, with a group CR of 0.21, making some of the inputs inconsistent (> 0.1), and indicating a high level of inconsistency. The northern region had a group CR of



	Blanking	Harvest residue management	Pest and disease control	Planting methods	Pruning	Seedling management	Soil preparation	Stump management	Vegetation management
■ GDM	0.064	0.398	0.088	0.148	0.020	0.034	0.187	0.017	0.044
▨ South	0.118	0.086	0.053	0.115	0.105	0.195	0.150	0.141	0.037
□ North	0.103	0.214	0.088	0.083	0.082	0.135	0.199	0.045	0.051

Silviculture Operations

Fig. 4 Grouped priority rankings of plantation managers for the northern and southern regions, and the group decision-making (GDM) priority rankings by the regional managers and R&D manager

0.03, with individual CRs ranging from 0.13 to 0.45. The GCI based on the plantation managers' inputs is classified as very high for both the south (86.2%) and north (89%) regions.

There is quite a shift in the priority ranking order of the silvicultural operations when comparing the aggregated southern and northern group priority rankings and the senior managers' GDM rankings (Fig. 4), however, there remains some similarity in the trends. Interestingly the outcome from the GDM priority rankings and the consolidated rankings from the northern region, both prioritized HRM as the highest and Stump M. as the lowest. While the southern region ranked Veg.M the highest and Seed M. the lowest. Even though there's dispersion in the rankings, there are close rankings such as the low ranking for PDC, Soil P. and Veg. M.

In-house R&D Capacity Evaluation

According to the results of the in-house research capacity evaluation, the cooperative lacks the capacity to conduct in-house research for HRM, Seed M., and Stump M. (Table 6). The RDT manager indicated that they do not have the machinery/equipment to do research related to these operations. This is due to the fact that these operations are mostly manual and access to machinery/equipment is expensive. However, for Soil P., Veg.M and pruning (*Acacia mearnsii* only), the strongest capacity the cooperative has is in terms of equipment/tools already available, therefore implementation of in-house research is possible. Hence, the high rankings for both indicators. For PM, PDC, and blanking activities, cooperatives can assist researchers by implementing and monitoring any trials or research performed on the cooperative's particular plantations. Overall, the cooperative's strongest capacity was implementation, followed by equipment device/tools. Research-based report writing was the cooperative's weakest capacity.

Table 6 Capacity indicators matrix for the in-house research capacity evaluated for each silvicultural operation by the R&D manager

Silviculture operations	Harvest residue management	Soil preparation	Planting methods	Pest and disease control	Blanking	Vegetation management	Seedling management	Pruning	Stump management	Overall research Capacity
Group decision-making rankings	**0.40**	**0.19**	**0.15**	**0.09**	**0.06**	**0.04**	**0.03**	**0.02**	**0.02**	
Experimental design	0.13	0.16	0.07	0.07	0.04	0.07	0.13	0.03	0.13	**0.11**
Equipment device/tools	0.13	***0.26***	0.19	0.07	0.17	***0.28***	0.13	***0.29***	0.13	**0.17**
Implementation	0.13	0.24	***0.23***	***0.24***	***0.31***	0.26	0.13	0.23	0.13	***0.19***
Data collection	0.13	0.14	0.22	0.18	0.17	0.18	0.13	0.13	0.13	**0.15**
Data analysis	0.13	0.06	0.06	0.11	0.07	0.04	0.13	0.08	0.13	**0.09**
Interpretation	0.13	0.08	0.12	0.11	0.14	0.09	0.13	0.12	0.13	**0.11**
Analysis of information from different sources	0.13	0.04	0.08	0.11	0.08	0.07	0.13	0.09	0.13	**0.10**
Report writing	0.13	0.03	0.03	0.11	0.03	0.02	0.13	0.03	0.13	**0.08**

The values in bold indicate the final GDM rankings and overall capacity evaluations. Values in bold-italics, on the other hand, indicate the highest ranking, while underlined values indicate the second-highest capacity indicator ranking for the operations

Discussion

This study aimed to support decision-making to inform the formulation of an R&D strategy relating to silvicultural operations and evaluation of in-house R&D capacity in a cooperative forestry setting. It further demonstrated the usefulness of an analytical hierarchy process (AHP) in firstly helping to formulate, and thereby make explicit, the preferences of both individual and regionally segregated groups of forest managers. Further, an ordinally ranked list of preferences, expressing the rank distance between preferences, was produced. The AHP showed the usefulness of structuring the R&D problems and assigning weights to inform strategic decision-making related to both research needs and where cooperatives should direct their investments in best serving their production needs. The method was identified as a useful tool to potentially empower key decision-makers of the cooperative and direct appropriate R&D advancements to their contexts as small-and medium-scale timber growers in a developing country. The result of the study provides input for management decisions to improve strategic decision-making.

The capacity evaluation indicated that the cooperative has a strong capacity for the implementation of research findings. The R&D manager clarified that their capacity extends to the implementation of research recommendations, provided the rest of the necessary activities prior and post implementation of the research are done by outsourced researchers. However, this does not apply to HRM, Stump M. and R&D on pests and diseases, since they rated the cooperative as not having the capacity for these due to a lack of the required equipment and tools to ensure successful implementation. Some additional factors are the costs and budget constraints for these investments. The decision to invest in R&D projects whether in-house, in collaboration with university researchers or through outsourcing, should commensurate with r the project benefits (Brenner 1994). With university collaboration for example, the cooperatives can fund postgraduate students to complete research that aligns with the cooperative's R&D strategy. Hence, the approach taken in this study to investigate priority needs and research capacity are important initial steps to inform R&D investment decision-making that align with the cooperative's strategy. In the case of the cooperative this would partly be ensuring the appropriateness of technology.

Method Used

The application of the AHP tool in this study demonstrated how individual decision-making (Survey 1) and group discussion-based decision-making (Survey 2) influenced the outcome of priority rankings when the tool is used on its own or hybridized with group decision-making (GDM). The use of the questionnaire in Survey 1 (individual decision-making) allowed plantation managers to contribute based on their own needs in their respective plantations. It also enabled them to have credible input in the decision-making process regarding R&D prioritization relevant to their needs as plantation managers. However, the development of the questionnaires can be time-consuming, which is a concern echoed by other authors (Qureshi and

Harrison 2003). It is also demanding since multiple testing from a scientific and application perspective is required to ensure a broad understanding for participants. Kühmaier and Stampfer (2012) warn about potential accuracy issues that may come with the use of indicators, and therefore encourages the use of appropriate indicators that serve the purpose of the question, while ensuring common understanding of each indicator. The study ensured common understanding of each of the indicators (silvicultural operations and capacity indicators) by including the descriptions of each in the questionnaires in all three Surveys. Even though individual attributes may be subject to selection bias due to the subjective evaluation of the large examples described in each attribute, the strength of the AHP partly lies in its ability to aggregate the rankings of multiple individuals into a group consensus. Piloting the questionnaire used in Survey 1 and 2 prior to distribution was beneficial in ensuring that it made sense to participants of both operational and strategic managerial levels. Finally, asking managers to engage and familiarize themselves with the preference rankings of plantation managers and reflection on R&D needs at both operational (plantation managers) and strategic management levels ensured informed decision-making and participation of key role players. Moreover, involving workers in decision-making activities has the potential to improve employee satisfaction and increase the performance of the organization (Cotton et al. 1988; Wagner 1994). In the context of this paper, one can trust that the final priority ranking (Fig. 4) is informed by diverse input and valuable information since the senior managers engaged with the individual rankings of the plantation managers prior to their GDM inputs.

When the scale of importance was modified to meet the evaluation of capacity indicators, it was discovered that the scale implies all traits included in the hierarchy are important. In this study, the value 1 (equal capacity) was assigned to operations where the RDT Manager evaluated research indicators as having "no capacity". This was determined to make sense because both indicators were thought to have an equal capacity, which in this case meant "zero capacity". The scale (Table 2) lacks a measure for "no importance," which would likely have been more appropriate for "no capacity."

The AHP method served as a useful tool for qualitative interpretation of decision-makers' subjective judgments. The inconsistency indicator for the judgments (pairwise comparisons) is both a valuable and, for practical purposes, a limiting aspect of the tool. Especially in situations where opportunities to amend judgments are not practical or possible. Consistency indicators showed a high level of inconsistency (>0.1) for most individual judgments; however, group consensus indicators fell within the "very high" classification for the regions and the managers' inputs. The "very high" consensus indicates that although the individual rankings differ, there is a high degree of overlap in priorities and consensus in the judgments (Goepel 2018). The participants, as far as it is known, did not discuss the subject prior to completing Survey 1.

The inconsistency in the inputs can be due to a variety of reasons such as the environment in which the plantation managers operated (operations active at the time of data collection), the individual interpretation of the AHP when reading instructions upon receiving the web-based survey leading to possibly different understanding/

misunderstanding of the purpose of Survey 1. Although all participants received the same descriptions and instructions in Survey 1. Depending on the method applied, some operations (e.g., pitting and planting) can influence each other, which can make the pairwise comparisons conflicting to the decision-maker making the rankings, and this can increase inconsistency. Most likely, the inconsistency is also partly due to the relatively large number of attributes (9) (silviculture operations). Saaty and Ozdemir (2003) argue that AHP is subject to human memory capacity limits, which according to Miller (1956) would be 7 ± 2 elements or chunks of information. Therefore, five would be the limit where inconsistency increases for some individuals (Saaty and Ozdemir 2003). Following this reasoning, it could be argued that the inconsistency is a complex measure that shows that the problem is fuzzy. Moreover, when presented with multiple paired alternatives one of the alternatives will prime the respondent to think about aspects that might have been "forgotten" before.

Group decision-making (GDM), involving only the three senior managers, showed an improved consistency ratio, although still not within the suggested threshold (<0.10), but pointed to the utility of group discussions before having respondents conduct priority rankings as suggested by Talbot et al. (2014). It should be reiterated, that the main interest of this study was to identify R&D needs in silviculture as per the inputs of plantation managers and senior management as influential decision-makers in R&D and resource distribution. Therefore, mathematically, the inconsistency values make their inputs contentious but do not make them irrelevant or untrue to their needs.

Priority Rankings

The priority ranking of HRM varied greatly between the southern and northern regions. During the group decision-making, the senior managers acknowledged that the priorities of the regions should not differ significantly due to the similar challenges they face, despite any differences in growing conditions. The high ranking of the harvest residue management after this session indicates that it remains a major challenge for both regions. These results complement the ordinal priority ranking of R&D in silviculture, which placed harvest residue management the top priority for not only small-and medium-scale timber growers, but large-scale corporate growers as well (Rietz et al. 2015). The main reasons given by the participants in the current study relate to the limitations on the allowable harvest residue burning time, resulting in harvest residue being left in the field for prolonged periods, reducing time available for site preparation. In addition, by finding a more environmentally friendly and economically sustainable solution they could reduce burning of harvest residue and minimize the environmental impact in the management of harvest residues. This was encouraged in both the findings in this study and Rietz et al. (2015). The impact of burning, especially on steep areas exposing topsoil, increases the severity of soil erosion during rainy season, which was a concern also noted in Rietz et al. (2015); the urgency and need for methods to reduce soil erosion after burning was also raised in both studies. Additionally, burning of all the harvest residue can reduce the long-term site sustainability due to the reduction of organic matter (Titshall et al. 2013).

Managers also acknowledged that it was difficult to compare the operations to each other due to how the operations can influence each other. For example, soil preparation and planting methods are sometimes integrated depending on the method used. R&D in soil preparation was ranked as the second highest priority for R&D needs. Soil preparation facilitates easier planting and can be done using motor-manual, manual or mechanized pitting implements which can influence pit size and quality (Hechter et al. 2020). Even though the method used in the study by Rietz et al. (2015) does not assign priority values to the ranking, the research needs in relation to soil preparation and planting methods was also considered among the top priorities.

Although R&D in pests and diseases was not highly prioritized in this study, it was clarified by the managers that it is a priority for the forestry sector. The cooperative already collaborates in research with the Forestry and Agriculture Biotechnology Institute (FABI) of South Africa. During the GDM process, one of the managers suggested that research in forest operations could include the use of drone technology to improve the application of control measures and monitoring infections. Drone technology R&D has already been conducted for its application in agricultural activities (Hafeez et al. 2022) and is projected to have a 50% adoption rate in forestry by 2025 (Ramantswana et al. 2021).

Capacity Evaluation

The manager mentioned that the cooperative's research capacity is low due to them not having an R&D department with a lab and full-time researchers. Hence, they rely heavily on collaboration with research institutes. This is not bad per se, it rather calls for more intentional approaches to R&D strategies. The benefits of in-house research are limited to ensuring strategic alignment with the company's goals and ensuring the sustainability of research projects they invested in.

Considering their low in-house capacity as a cooperative, they stand a greater chance of succeeding with R&D through collaborative research or open innovation. Collaborative research will play to the cooperative's strengths, which in this case is the implementation of research. Since the cooperative already has an openness to interacting with academic and research institutes, part of their R&D strategy could include aligning postgraduate students' projects with their short-term R&D goals. Rodrigues and Delfim (2022) propose that partnering with appropriate and leading R&D institutions is critical to being able to innovate. With long-term R&D goals, the strategy can leverage collaboration and open innovation approaches. Open innovation permits outsourcing external R&D sources and cost reduction. When open innovations are implemented, innovation also increases in agility, flexibility, and throughput (Jelinek et al. 2015). Cooperatives have a considerably larger chance of success and advancements if they implement open innovation in their strategy. The collaboration and [open innovation] approach will support focus on improving the quality of decision-making through anticipating and preparing for customer [members'] needs (Matheson et al. 1994). Cooperatives can strategize well ahead in their investments, as mentioned by Kronholm (2016), identify appropriate institutions to collaborate with based on the areas in which they lack capacity in, or outsource research skills as needed.

In the case of cooperatives, this will include the member-specific, long-term needs and challenges as identified by previous authors (Kronholm 2016; Upfold et al. 2015). The new membership types projected (Kronholm 2016; Upfold et al. 2015) with potentially new challenges and research needs will require strategic R&D approaches investigating means of enhancing technology adoption that aligns with their members' needs. This could be enhanced by cooperatives forming even stronger collaborations with research institutes by diversifying their investments based on the knowledge available in the various institutions (Weiss et al. 2012). The cooperative will benefit more from research collaboration when they have an informed R&D strategy that aligns with the business strategy (Herfert and Arbige 2008).

The cooperative's strategy of utilizing its own plantations to provide and support the implementation of research can help the cooperative stay ahead in meeting some foreseen silviculture operational needs. The cooperative could improve their own operations through appropriately prioritized R&D investments that benefit their members as well. Putting processes in place that encourage technical staff to work across broad core research areas, such as focusing on programs around four critical strategic thrusts that require the input and involvement of people from diverse disciplines (Comstock and Sjolseth 1999).

The application of the AHP methodology in this study demonstrated the flexibility of such a tool to demonstrate the development of an R&D strategy that takes into consideration various factors. While the approach taken helps to inform the decision-making process, it certainly isn't the final step. There is a need to further identify the risk levels of the different proposed research investments, and the period of each project. The risk level, the feasibility of investment, time (period) and relevance to members' needs should all be considered and weighed against each other. Future studies could look into applying these next steps to further identify and prioritize R&D needs factoring the mentioned considerations.

Conclusions

The outputs of this study aid in informing R&D strategy based on individual input and discussion-based priority rankings for the cooperative. Cooperatives should execute the AHP study at several intervals in the year since some inputs were attributed to the current or seasonal concerns at the time of data collection. Exploring priority rankings at different intervals may provide a clearer picture of which persistent research needs to be prioritized. It is proposed that cooperatives enhance and invest in more intentional strategic approaches to collaborate with institutions in carrying out research that aligns with their strategies to enhance research progress and development.

Training participants on using a digital AHP tool, instead of a questionnaire with lengthy words, will help shorten the period of analysis and data processing.

Additionally, when participants are aware of inconsistencies in their inputs, they can make amendments within the organization. This could also reduce the inconsistencies identified in the study.

Ranking silvicultural research needs per operational method could be the next beneficial phase, followed by evaluating and classifying research capacity of collaborative research institutions. Understanding which specific research capacities different institutions have will improve strategic decision-making in relation to R&D investments and aligning capacities with cooperatives' needs.

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Declarations

Conflict of interest No conflict of interest reported by any of the authors.

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