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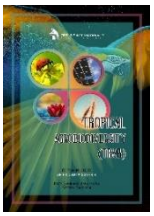

RESEARCH ARTICLE

CHARACTERIZATION OF THE DIFFERENT MANAGEMENT PRACTICES AND FACTORS AFFECTING EUCALYPTUS PRODUCTION IN THE THREE AGROECOLOGICAL ZONES OF UGANDA.

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ABSTRACT

Eucalyptus is one of the most widely planted exotic tree species grown in Uganda especially among rural households and has gained economic importance in the different agro ecological zones. Currently, Uganda smallholder farmers mainly establish Eucalypts woodlot as a part of livelihood portfolio for meeting both household wood consumption and generating income. However, the agronomic management practices which influence final yield as well as factors influencing eucalyptus production are not well packaged and understood in the different agroecological zones. This makes it difficult for researchers to develop integrated soil fertility package of the enterprise to ensure its sustainability. Primary data on the different management practices, production systems, eucalyptus types and reasons for their preferences were collected from 150 randomly selected Eucalyptus producer households through pretested questionnaires in Lake Victoria crescent (LVCAEZ), Western and Southwestern agroecological zones represented by Mpigi, Kabarole and Rakai, respectively. Multiple linear regression analysis was employed to determine the significant variables affecting the level of eucalyptus production. Also, multi criteria analysis was conducted to characterize the different management practices of eucalyptus in the different zones.

The findings indicated that the main types of eucalyptus varieties cultivated in the three agroecological zones are the Local (*E.grandis*) and improved GU7. Moreover, the survey results demonstrated that factors such as farmers' education level, age, landholding size, gender, and land tenure system positively and significantly impacted eucalyptus production levels across these zones ($P<0.05$). Conversely, marital status and ownership of intercrops within eucalyptus stands did not show a significant effect on production levels across the zones. Additionally, the study highlighted that among various management practices, land preparation followed by row planting were the predominant methods employed by farmers in all three zones. Furthermore, it was observed that fertilizer application was not prioritized by farmers in the Western Highlands and LVCAEZ, except in the Southwestern zone, where it was acknowledged but not widely implemented due to its high costs. To ensure the sustainability of eucalyptus production in Uganda, it is imperative for researchers to develop standardized management practices tailored to the specific agroecological zones. Foresters and extensionists should consistently consider the socio-economic factors influencing eucalyptus production in these zones to enhance productivity and sustainability.

KEYWORDS

Management Practices, Eucalyptus, Farmers, Agroecological Zones, Uganda.

1. INTRODUCTION

Currently, small-scale farmers in Uganda predominantly cultivate eucalyptus woodlots as a key component of their livelihood strategy, serving to meet both household wood requirements and generate income. Eucalyptus trees are cultivated for various purposes, including providing fuel for tobacco curing, domestic and industrial energy needs (such as drying tea and sugar, baking, and charcoal production for steel and cement manufacturing), supplying posts and poles for fencing and electricity transmission lines, as well as serving aesthetic purposes as ornamental trees in urban areas. Moreover, they contribute to lowering the water table in wetlands and rehabilitating infertile soils or degraded land for productive use (Zerga et al., 2021)

In nations like Uganda, Eucalyptus farming is often seen as a profitable venture due to its low production costs (Jacovelli, 2014). Nonetheless, there exists a significant gap between the demand and supply of wood, resulting in the overexploitation of natural resources and increased deforestation in recent times. Eucalyptus is being promoted as one of the tree species to address the rising demand for forest products and counteract deforestation (Herrera, 2018; Silva et al., 2019). It thrives in poor soil conditions and matures more quickly compared to many indigenous tree species like *Cordia Africana* (Negash, 2021). Additionally, eucalyptus plays a vital role in ensuring food security for smallholder

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farmers in rural areas during times of hardship, owing to its versatility (Isukuru et al., 2023; Nambiar, 2021). However, in certain regions, farmers have converted land previously used for food crop cultivation to eucalyptus farming, potentially jeopardizing the country's food security.

Considering the ongoing importance of Eucalyptus production, it is crucial to establish a comprehensive information foundation to facilitate the sustainable management of eucalyptus production systems in Uganda. A pivotal approach entails delineating diverse management practices and pinpointing the factors that impact Eucalyptus production systems across the country.

2. Materials and Methods

2.1 Description of the study areas

The research was conducted across three distinct agroecological zones: Lake Victoria, Southwestern, and Western, which are represented respectively by the districts of Mpigi, Rakai, and Kabarole. These zones were chosen due to their notable increase in eucalyptus production compared to other regions in Uganda. The geographical coordinates of the representative districts are as follows: Mpigi (latitude: 0°04'60.00''N, longitude: 32°00'0.00''E), Rakai (latitude: 0°39'59.99''S, longitude: 31°24'59.99''E), and Kabarole (latitude: 0°27'0''N, longitude: 39°07'0''E). The altitude of the study districts ranges from 1,280 meters for Rakai and 1,217 meters for Mpigi to between 1,300 and 3,800 meters above sea level for Kabarole.

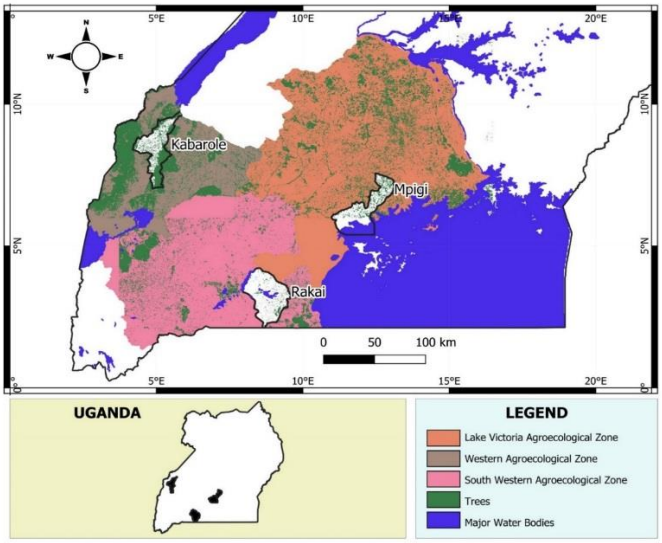

Figure 1: Map representing districts of study in the three agroecological zones. The green color represents trees of approximately 15 m height or higher in 2022 as derived from Land use/Land cover raster file built from Sentinel-2 of resolution 10 m.

2.2 Sampling procedures and data collection

A combination of quantitative and qualitative data was collected from both primary and secondary sources for this study. Secondary data was collected from relevant sources of published and unpublished documents to gain a general insight on the issue of enquiry. Then primary data was collected from household heads and community leaders through household interviews, key informants interviews and focus group discussions. The interview schedule consisted of semi-structured questions was pre-tested prior to the actual data collection. It included several aspects such as the socio-economic, demographic, and institutional characteristics of household heads, their practices in eucalyptus plantations, Eucalyptus production and marketing embodied in the household farming system. The interviews were administered with 150 randomly selected sample Eucalyptus farmers across the three zones.

2.3 Scoring of the different management practices across the agroecological zones

Ranking method (table 2) was used to determine the most prioritized management practices in eucalyptus plantations by farmers across the three zones according to their order of importance by assigning them scores. A scale of 5-1 was used by farmers in form of a focus group discussion per district to rank the most to least priotised management practice. The scale was described as follows: 5 (excellent), 4 (very good), 3 (good), 2 (fair) and 1 (poor).

2.4 Data Statistical Analysis

The data was subjected to multivariate analysis to generate relatively uniform clusters of eucalyptus production systems that was further analyzed for differences in underlying socioeconomic/biophysical drivers for growing eucalyptus and agronomic management practices adopted for achieving the prioritized outputs in the study zones. R programing software was used for data analysis.

3. Results and Discussions

3.1 Dominant eucalyptus production systems across the study agroecological zones

Survey results showed that woodlot production system is the main system across the three zones followed by boundary planting with Western Highlands significantly taking lead followed by Lake Victoria Crescent Agroecological Zone with Southwestern agroecological zone emerging least. Similar results obtained in 2017 by two researchers who during a survey in Lake Tana watershed Ethiopia disclosed that the main plantation production practice was woodlot, cropland boundary plantation, and road borders plantations to fulfil the needs for fuel wood, construction, and income generation (Figure 2) (Tefera and Kassa, 2017).

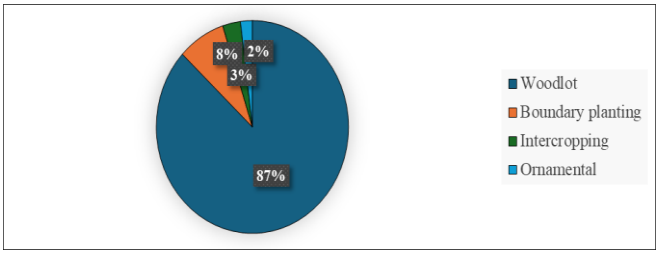

Figure 2: Dominant production systems across agroecological zones under study

3.2 Demographic and socioeconomic characteristics of sample farmers in the study areas.

Results in table 1 revealed that 86.67% of the surveyed household were male and they were significantly different (P<0.033) across districts. Then, 82.22% of the interviewed farmers were married with no significant difference across districts. Again, out of the population interviewed, only 5.19% was illiterate and significantly different across districts (P<0.035). The chi-square test results also indicate that the land ownership (P<0.000), Community as the intercrop owner (P<0.000), Age-Adults (P<0.017) and Land size (P< 0.000) have significant association with eucalyptus production across districts.

3.2.1 Gender

The study's findings from table 5 revealed a significant disparity in engagement levels between males and females in Eucalyptus production across the districts, with males showing higher involvement. This trend can likely be attributed to the traditional allocation of resources such as land, where males, typically considered family heads, receive a larger share. Additionally, women's participation in perennial crop production tends to be limited, as men often prioritize projects that yield higher income, leaving women primarily engaged in food crop cultivation to support their families.

These results align with two researchers in 2012 who highlighted the insufficient gender expertise and competence, along with limited access for women and youth to leadership roles, hindering their participation in decision-making processes (Kiptot and Franzel, 2012). Similarly, women may face challenges in utilizing available technologies, information, and services due to gender gaps in accessing finance and markets (Kamberidou, 2020)

3.2.2 Education Level

The study findings revealed a notable trend: farmers with a secondary education level demonstrated higher involvement in eucalyptus production across various districts compared to those with other educational backgrounds (table 1) This suggests that increased education attainment among farmers correlates with improved access to valuable information on optimal agricultural techniques and marketable crops such as eucalyptus. These findings align with prior research conducted in Nepal, which similarly highlighted the positive impact of education on agricultural productivity. Specifically, education was found to enhance

farmers' decision-making skills, thereby augmenting their technical efficiency their ability to optimize input usage and make economically sound decisions. This assertion is supported by studies by (Demarchi et al., 2021; Mulu et al., 2022; Nyeko et al., 2007). Moreover, the notion that education serves as a valuable mechanism for enhancing agricultural productivity (Steven et al., 2024).

Information and services can be attributed to structural constraints, including both formal and informal institutions, as well as gender norms dictating roles, resource access, decision-making, and mobility within the community as identified by (Spangler and Christie, 2020).

3.2.3 Size of Land Holding

The size of land holdings emerges as a critical factor influencing farmers' decisions regarding the establishment or planting of eucalyptus trees (table 1). This segment of the analysis focuses on the landholding characteristics of the households under study and their implications for eucalyptus tree planting decisions. Regression analysis indicates a statistically significant positive relationship between farmers' land sizes and their likelihood of planting eucalyptus trees, with significance observed at ($p<0.033$) level. Holding all other factors constant, farmers with sufficient land to produce food for their families are more inclined to allocate a portion of their land to eucalyptus tree cultivation compared to those with smaller land holdings. Farmers with smaller land holdings tend to prioritize crop production and other activities such as fruit and vegetable cultivation over tree planting like eucalyptus. Families with larger land holdings often diversify their land use to generate additional sources of income, including crop cultivation, fruit and tree planting, vegetable farming, and animal husbandry. Therefore, the size of farmland owned by farmers emerges as a crucial determinant shaping their decisions regarding eucalyptus tree planting. These findings align with results from various studies, by multiple researchers (Amare and Darr; 2024; Garen et al., 2009; Miller et al., 2017; Nigussie et al., 2021; Nöldeke et al., 2021; Spencer et al., 2021).

3.2.4 Age of the Surveyed Farmers.

The age of farmers emerged as a significant and positively correlated factor influencing their decision-making regarding the planting of eucalyptus trees, with a significance level of ($P<0.05$). Holding other factors constant, as farmers' age increases, their propensity to plant eucalyptus trees also increases, with a probability value of *0.017*. The findings indicate that adults tend to be more actively involved in eucalyptus production across different districts. Older farmers may have less inclination or ability to invest in the cultivation of seasonal crops, fruits, and vegetables, as these require more intensive attention compared to perennial crops or trees like eucalyptus. In contrast, younger farmers often prioritize seasonal crops, which offer quicker returns compared to perennials that take longer to mature. These results are consistent with several studies (Sherrington et al., 2008; Slegers, 2008, Adhikari et al., 2018; Rossi and Hinrichs, 2011). However, it's worth noting that a study by found that respondents' age had no significant effect on their decision-making regarding eucalyptus tree planting (table 1).

3.2.5 Land Tenure

Table 1 showed that all land tenure systems significantly influenced eucalyptus production across districts. This could probably mean that irrespective of the land tenure system, it all depends on the commitment of the farmers towards eucalyptus production. However, these findings are contrary to those of many previous researchers. For instance, Brasselle et al. (2002) found out that land tenure especially that one on fixed landownership significantly influenced level of land productivity in Burkina Faso (Brasselle et al., 2002). Key informants indicated that eucalyptus is considered as a major cash crop in the study area being one of the major sources of cash income for most households.

Table 1: Demographic and socioeconomic characteristics of sample farmers in the different study areas

Variable	Kabalore (n=63) (%)	Mpigi (n=40) (%)	Rakai (n=32) (%)	Pooled (n=135) (%)	Chi-square (*P-value*)
Sex					
Female	19.05	15.00	0.00	13.33	6.80 (*0.033*)
Male	80.95	85.00	100.00	86.67	
Married (1=Married, 0 Not married)	76.19	90.00	84.38	82.22	3.32 (*0.190*)
Education Level					
None	0.00	12.50	6.25	5.19	13.54 (*0.035*)
Primary	0.00	0.00	3.13	0.74	
Secondary	41.27	40.00	53.13	43.70	
Tertiary	58.73	47.50	37.50	50.37	
Land Tenure					
Mailo	0.00	12.50	0.00	3.70	12.33 (*0.002*)
Free hold	87.30	7.50	100.00	66.67	91.08 (*0.000*)
Lease	12.70	80.00	0.00	29.63	70.80 (*0.000*)
Owner Intercrop					
Self	47.62	42.50	62.5	49.63	3.04 (*0.219*)
Community	0.00	27.50	6.25	9.63	21.81 (*0.000*)
Neighbour	4.76	5.00	0.00	3.70	1.62 (*0.446*)
Age Category					
Youth	7.94	15.00	0.00	8.15	12.03 (*0.017*)
Adults	66.67	80.00	84.38	74.81	
Elderly	25.40	5.00	15.63	17.04	
Land Size					
Average land size	2.194(2.487)	13.60(14.78)	3.53(2.67)	5.89(9.67)	F=24.69 (*0.000*)

3.3 Characterization of management practices in the agroecological zones.

3.3.1 Land preparation and spacing

The survey results, as depicted in table 2, highlight that land preparation followed by row planting are the primary practices prioritized across the three agroecological zones. This preference is likely attributed to the necessity of ploughing to loosen the soil for optimal root development. However, the study uncovers a notable lack of understanding among farmers regarding the optimal management practices for maximizing eucalyptus yield and profitability for specific cultivars within the zones. These findings resonate with those of researchers focusing on sustainable management of *Eucalyptus pellita* plantations, which revealed widespread deficiencies in prioritizing appropriate agronomic practices among farmers in equatorial and tropical environments, often resulting in subpar eucalyptus products and financial losses (Hutapea et al., 2023). Conversely, as indicated in table 2, the survey results suggest that farmers across the three zones prioritize land preparation, which is a commendable practice. However, it is noteworthy that this practice is often executed inadequately, with a majority of farmers relying on machinery, as revealed by the survey. Inappropriate land preparation techniques, such as excessive machinery use, can lead to soil compaction, erosion, nutrient depletion, and topsoil displacement, all of which

adversely impact tree growth (Ayub et al., 2020; Baumhardt et al., 2015). Particularly concerning are the potential long-term consequences on soil health, especially in short rotations, where frequent heavy equipment usage may exacerbate site damage unless proactive measures are taken to mitigate soil degradation. Furthermore, the study underscores a concerning trend where many farmers neglect prioritizing fertilizer application in their eucalyptus plantations, despite significant nutrient depletion, especially during harvesting. This oversight poses a significant threat to future eucalyptus yields and wood quality, emphasizing the importance of addressing nutrient management practices to ensure sustainable productivity and profitability in eucalyptus cultivation.

The study in table 2 again highlights a concerning trend among farmers, where many overlook standard spacing recommendations, ultimately impacting final yield. Previous research underscores the critical role of tree spacing in shaping tree growth dynamics, primarily by regulating competition for essential resources like nutrients, water, and light (Gabira et al., 2023). While wider tree spacing tends to promote larger individual tree diameters, it comes at the expense of stand-level productivity (Pretzsch and Schütze, 2021). However, the (Liu et al., 2022). Additionally, wider tree spacing facilitates lateral expansion of tree crowns and enhances carbohydrate production through photosynthesis, with these resources primarily allocated to radial stem growth and branch development (Kholdaenko et al., 2022; Vospernik et al., 2010). Moreover, tree spacing significantly influences timber quality, particularly in forest plantations aimed at sawlog and veneer production. Trees grown closer together tend to have smaller branch diameters and knot sizes and undergo earlier self-pruning compared to those with wider spacing (Pretzsch and Rais, 2016). The wood industry actively avoids larger knot sizes due to their adverse effects on sawn timber quality, impacting structural strength and surface appearance, while the pulp and paper industry similarly seeks to minimize knot size due to its detrimental effects on pulp quality and processing operations (Bourscheid et al., 2023; Cáceres et al., 2017). Despite the standard spacing recommendation of 3 m x 3 m, many farmers reported utilizing a narrower spacing of 2 m x 2 m, potentially compromising final yield, particularly for improved varieties with wider canopies. However, it's essential to consider site-specific conditions when determining optimal spacing. For instance, in drier sites, wider tree spacing can alleviate competition for water resources (Gonçalves et al., 2017), whereas in typhoon-prone areas, narrower spacing may offer protection against windthrow (Ashton & Zhu, 2020). Adjusting tree spacing according to site conditions is crucial for optimizing resource utilization and maximizing overall productivity in tree plantations.

3.3.2 Thinning and Pruning

The findings from this study, as presented in the provided table, reveal that most farmers do not engage in thinning or pruning practices within their plantations. These activities are only minimally observed in the case of the local cultivar (*E. grandis*) across the three specified zones. However, what is commonly perceived as thinning and pruning by farmers primarily involves the extraction of firewood and small poles for construction purposes. Alternatively, many farmers allow the plantation to naturally regenerate, a process referred to as coppicing. Coppice regeneration is notably more cost-effective to establish compared to growing seedlings or clones and can potentially reduce production costs by up to 50% (Atkinson, 2009; Crous and Burger, 2015; Leslie et al., 2020; Ramantswana et al., 2020). Coppice stands also exhibit superior growth performance in comparison to seedlings and clones, particularly in the initial stages, owing to their carbohydrate reserves (Rodrigues et al., 2021) and well-developed root systems that facilitate enhanced access to water and nutrients (Attipoe et al., 2023; White, 2019). Previous research has similarly highlighted equivalent or greater productivity of eucalyptus plantations derived from coppice as opposed to seedlings (Ferraz Filho et al., 2014; Hardiyanto et al., 2022). Notably, in South Sumatra, *E. pellita* coppice has been reported to exhibit higher productivity than seedlings, with stand volume from coppice being 76.3 m^{-3}ha greater than that from seedlings. However, a group of researchers present contrasting findings, suggesting that coppice productivity is contingent upon site conditions and the survival of trees from the previous rotation (Spinelli et al., 2016). Effective coppice management following clear-felling is also identified as a crucial factor in the success of plantation endeavors (Dickmann, 2006; Walters et al., 2008)

Table 2: Ranking of the management practices in eucalyptus production systems in the three districts.

District	Land preparation	Row planting	Spacing	Fertilizer application	Weeding	Thinning (local) &pruning	Average
Rakai	5	4	2	5	2	1	**3**
Kabarole	5	3	4	1	2	1	**3**
Mpigi	5	4	2	1	2	1	**3**

Ranking; 5=Very good, 4=good, 3=Fair, 2=poor, 1=Very poor

3.4 Variety Preferences

Results in table 3 present the farmers' eucalyptus variety preferences across different districts, highlighting significant differences observed in their choices. In Kabarole district, 27.08% of farmers preferred the GU7 variety, while a majority (54.05%) favored local varieties ($p < 0.001$).

Conversely, in Mpigi district, the trend was notably different, with a substantial 70.83% of farmers opting for GU7 variety compared to only 5.41% for local varieties ($p < 0.001$). Similarly, in Rakai district, a minimal 2.08% of farmers preferred GU7, while 40.54% favored local varieties ($p < 0.001$). These findings underscore the district-specific preferences among farmers, which could be (Gebru et al., 2019; Tega and Bojago, 2023; Tesfaw et al., 2022).

Table 3: Farmers variety preference per district

District	GU7 (n=48) (%)	Local (n=74) (%)	(*P-value*)
Kabarole	27.08	54.05	<0.001
Mpigi	70.83	5.41	<0.001
Rakai	2.08	40.54	<0.001

Table 4: Reasons for the preference of the eucalyptus GU7 variety across different districts.

Reasons	Kabarole (n=25) %	Mpigi (n=60) %	Rakai (n=1) %	(*P-value*)
Quick maturity	28.00	46.67	100	*<0.001*
Disease resistant	0.00	26.67	0.00	*<0.001*
Very strong	28.00	1.68	0.00	*<0.001*
Does not break away	24.00	0.00	0.00	*<0.001*
Grows straight and tall	0.00	8.33	0.00	*0.042*
Ready market	0.00	6.68	0.00	*<0.001*
Good timber	4.00	5.00	0.00	*<0.001*
Does not take too much water	12.00	0.00	0.00	*<0.001*
Drought tolerant	4.00	3.33	0.00	*<0.001*
Small branches to intercrop	0.00	1.68	0.00	*<0.001*
Cheap	0.00	0.00	0.00	*<0.001*
Quality firewood	0.00	0.00	0.00	*<0.001*

From table 4, results reveal that in Kabarole, 28.00% of respondents cited quick maturity as a primary reason, followed by very strong attributes (28.00%) and resistance to breaking away (24.00%). Mpigi district showed a higher inclination towards quick maturity (46.67%) and disease resistance (26.67%), whereas in Rakai district, respondents unanimously favoured the variety for its quick maturity (100%). Statistical analysis revealed significant differences in preferences across districts for all reasons ($p < 0.001$), emphasizing the regional variations in the perceived benefits of eucalyptus GU7. Additionally, in Mpigi, factors such as growing straight and tall (8.33%), ready market (6.68%), and small branches suitable for intercropping (1.68%) also influenced preference, albeit to a lesser extent. Conversely, in Kabarole, aspects like drought tolerance (4.00%) and suitability for intercropping (0.00%) were mentioned, while in Rakai, these factors were not reported. The table underscores the nuanced considerations driving the selection of Eucalyptus GU7 variety, which encompass ecological, economic, and agricultural factors unique to each district (Cidrás and Pauli, 2021; Grossman, 2015; Levers et al., 2014). Moreover, research conducted in 2022 revealed that farmers prioritize crop varieties based on their environmental adaptability and yield stability (Marenya et al., 2022). The same study also uncovered those variations among farm households, including household characteristics, resources, limitations, and levels of access to agricultural extension services, significantly influence farmers' individual assessments of the value of crop variety traits.

4. Conclusion and Recommendations

Findings of this survey revealed that woodlot production is the main production system followed by boundary tree planting across the three agroecological zones under study. The study also revealed that farmers do not follow the standard management practices during the entire eucalyptus production cycle. In order to ensure a sustainable eucalyptus production system in Uganda, researchers should develop standard eucalyptus management practices specific to particular cultivar and by a given agroecological zone. Foresters and extension workers should consistently consider the socio-economic factors affecting eucalyptus production in various regions to enhance planning, management, and the sustainability of eucalyptus systems.

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