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The Silviculture of Woodlots of Smallholder Forest Producers in Mufindi District, Tanzania: Knowledge and Treatments

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ABSTRACT

Smallholder forestry is experiencing many challenges like limited understanding of silvicultural treatments to impact the quality and performance of woodlots. This study determined the silvicultural treatments of smallholders in Mufindi district by interviewing 78 respondents then assessing the silviculture of 78 woodlots in 13 sampled villages. The study found out that more than 80% of smallholders had a certain level of understanding of some treatments like weeding and pruning. A major source of knowledge was personal experiences from fellow farmers and Sao Hill Forest Plantation. Based on market demand, *P. patula* and *E. grandis* were the most planted species in the woodlots. Smallholders reported planting trees at a spacing of 3 x 3 m without clear knowledge on factors to consider for initial spacing. Also, reported harvesting trees for sawn timber at 8 - 13 years and transmission poles at 6 - 8 years. Contrary to knowledge, the assessment found out that majority of woodlots had a spacing of 2.5 x 2.5 m. Many woodlots were poorly pruned and surrounded by shrubs which affected timber quality. Generally, woodlots management was unsatisfactory due to insufficient technical knowledge. Thus, more training is needed to strengthen smallholder forestry to ensure sustainable tree farming.

Keywords: Tending - Demonstration Plots – Extension Services – Performance

INTRODUCTION

The cornerstone of rural economies in developing countries like Tanzania is firmed in millions of smallholders and family farmers (FAO 2017). Apart from agriculture-based economies, forests and other natural environments are essential for families' subsistence and life earnings with the estimation of 28% contribution to rural household income (Ali *et al.* 2020, Angelsen *et al.* 2014). One-third of global productive plantations fall under smallholders' ownership while corporates have ownership of less than one-fifth of the global plantation area. Despite these statistics, a big share of trees planted by smallholders in woodlots is excluded in official statistics (Indufor 2017). Studies found out that, smallholders will best meet the challenges of multifunctional landscapes through afforestation and sustainable forest management as far as the targets of economic benefits, secured household's food supply, and adaptation to climate change are integrated into rural livelihood strategies (Harvey *et al.* 2014).

Proper management of forests is highly needed to make smallholder forestry sustainable for both livelihood and rural economy. Options in forest management include well-planned management and expanding forest ecosystems by increasing the area of plantations/woodlots and agroforestry under proper silvicultural treatments (Walker *et al.* 2008, UN-DESA 2021). A primary objective of silviculture in forest management is to spread risk in a way that reduces the impact of damaging events and increases the resilience of forests. This requires predictive forest planning informed by knowledge of the types of damaging events likely for the region and of the sites under management (Duncan 2008).

Proper species-site matching, sound seed/seedling sources, and other silvicultural treatments like intensive site preparation, proper weeding, pruning, thinning and harvesting cycle can have an important influence on both plantation/woodlot growth and yield. For sustainable woodlots management, these treatments add value to wood properties, protect the forests from fire and diseases as well as enhance good tree increments resulting in high timber value (Forrester *et al.* 2010). Silviculture outcomes to smallholder forests can strengthen the afforestation speed of this very important rural group. These can be attained through passing silviculture knowledge to smallholders for potential tree planting and proper management.

Mufindi district is experiencing an increase of small-scale woodlots owned by smallholders, cooperative groups, schools, and religious organizations (Ngaga 2011). However, the rate at which forest area increases to cover the wood gap is low because of poor tree survival, retarded growth of trees, and severe fire events. Partly, these setbacks are influenced by the insufficient silvicultural treatments and improper forest management among smallholders as this knowledge is obviously available to professional foresters and big forest companies (Held et al. 2017). Challenges like poor tree survival facing smallholder forestry in Tanzania as a result of missing proper silvicultural treatments have negatively affected the afforestation motivation among smallholders. Many forestry studies about smallholders in Mufindi have focused on the motivation factors to woodlots development and its contribution to rural income (Nkwera 2010, Singunda 2010). No studies have been published on conditions influencing successful silvicultural outcomes based on affordable practices to local farmers in Mufindi district. The main objective of this study was to determine silvicultural treatments of woodlots of smallholder forest producers in Mufindi district through assessing the understanding of different silvicultural treatments among smallholders as well as evaluating silvicultural treatments practised by smallholders in their woodlots.

MATERIALS AND METHODS

Study Area

The study was conducted in Mufindi district one of seven districts of Iringa region of Tanzania (8°-9°S; 30°-36°E) (URT 2013). The district lies at an altitude of 800 to 2200 m.a.s.l. with an average annual temperature of 17.1℃. It experiences a well-distributed rainfall ranging from 950 to 1,600 $mmyr^{-1}$. Main commercial crops are tea and forest plantations (Singunda 2010). Mufindi district has a total area of 712,200 ha divided into 5 Divisions, 30 Wards, 125 Villages, and 608 Hamlets (URT 2013). Nowadays, Mufindi district is a centre for forestry and different tree-planting programmes (Nkwera 2010). For instance, the largest state forest plantation (Sao Hill Forest Plantation (SHFP)) occupies a large part of this district (Singunda 2010).

Sampling Design and Data Collection

Both purposive and random sampling methods were used to select samples for the interviews and the field survey in the woodlots. A total of 13 sample villages of Vikula, Ihalimba, Nundwe, Mwitikilwa, Ifwagi, Itona, Ikongosi, Igowole, Ibatu, Nzivi, Mninga, Mkalala, and Kasanga (10% of all 125 villages) of Mufindi district were selected based on research objectives and experts' recommendations. To assess the understanding of different silvicultural treatments among smallholders, 78 direct semi-structured interviews with smallholders under purposive sampling were conducted. Direct field woodlots assessments with the cluster sampling method were applied to evaluate the quality of silvicultural treatments practised by smallholders in their woodlots. Woodlots were practically assessed whereby the size, quality, and intensity of different silvicultural treatments were evaluated. Moreover, literature on silviculture practices and smallholder forestry was used to discuss the field results as a secondary data source.

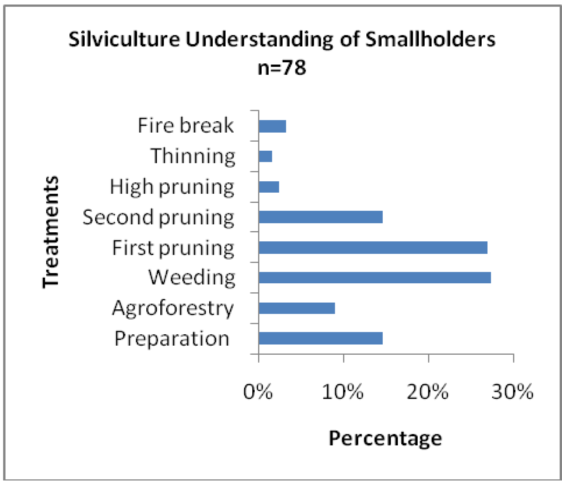
Data Analysis

The content analysis method was used to analyse qualitative data like discussion information and documented information from the survey. Microsoft Excel with its statistical instruments was used to process and analyse both quantitative and qualitative data from the field. Descriptive statistics were employed to analyse quantitative data. SPSS Statistics software was used to analyse smallholders' knowledge qualitative data and woodlots silvicultural treatments (size, quality, and intensity) data. The analysis output was then summarized and presented in the form of numbers, percentages, tables, and graphs.

RESULTS

Understanding and Source of Silviculture Knowledge

From this study, 92% of smallholders in Mufindi reported having an understanding and experience on early-stages silviculture from site preparation to second pruning. Only a few reported having additional knowledge on high pruning, thinning, and fuel-break as silvicultural treatments (Figure 1). About 75% of smallholders reported the silviculture knowledge source to be a personal experience from their fellow farmers as well as from the big state forest plantation – Sao Hill Forest Plantation (Figure 1). Moreover, extension services by state forest officers have contributed to about 15% of the silvicultural knowledge while Non-Governmental Organizations (NGOs) like Forestry Development Trust (FDT) and Participatory Plantation Forestry Programme (PFP), and schools contributed 5% each. This study found out that the forestry extension services grew with time from the year 2015 and tree planting techniques were the most offered knowledge to smallholders with 43%.



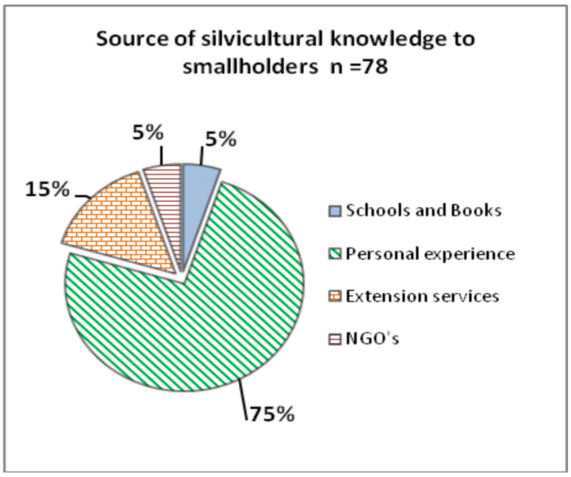


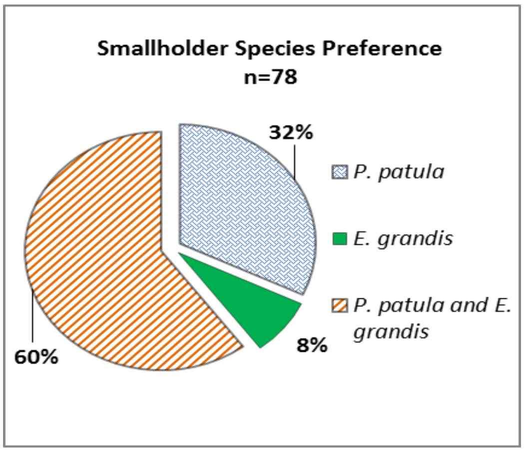
Figure 1: Types of silvicultural knowledge and providers in Mufindi district, Tanzania.

Silvicultural Treatments of Smallholders

Tree Species Selection

More than 50% of smallholders in Mufindi prefer to plant both *P. patula* and *E. grandis* for different reasons (Figure 2). Species preference is highly influenced the market demand direction. A major factor behind *P. patula* preference among smallholders is the big timber market (55%) whereby this species is the most traded tree species at the local and international markets. Other factors were the species being friendly to food crops through agroforestry practices, being a non-coppicing species thus can be alternated with other tree species. Further, pine harvested woodlots are considered more fertile to food crops.

E. grandis is in favour of some smallholders because of rising market demand with a good price (43%); fast growth behaviour; multiple uses such as transmission poles, sawn timber, and fuel-wood as well as a coppicing nature which reduces planting cost for the next rotation. The big challenge mentioned over *E. grandis* was the difficulty to change a harvested woodlot into another use or plant another species as a result of its coppicing behaviour and having a very long taproot thus difficult to uproot the stumps.



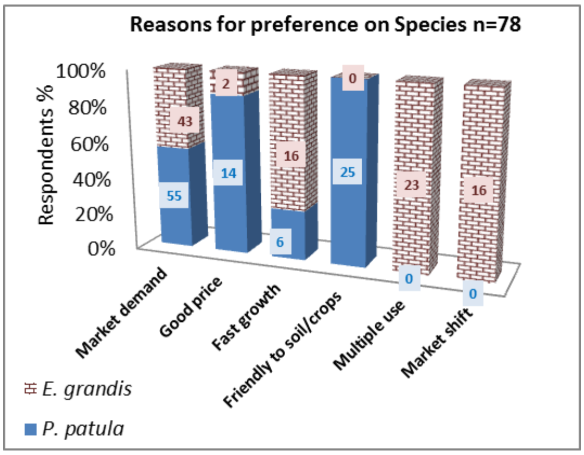
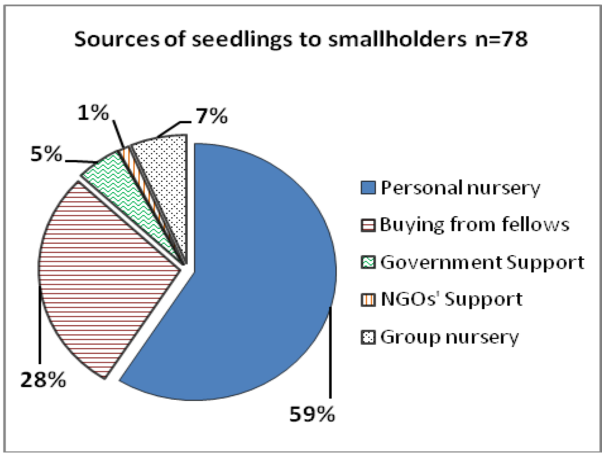


Figure 2: Smallholders' species preference and reasons for the preference in Mufindi district, Tanzania.

Seeds and Seedling Sources

Results indicated that 59% of smallholders in Mufindi understand and raise their seedlings in the local nurseries while 28% establish woodlots through buying seedlings from fellow farmers (Figure 3). Thus, more than 80% of smallholder woodlots were established from the locally raised seedlings. Furthermore, this study found that about 57% of seeds used to raise smallholder seedlings were locally collected from old woodlots while 25% of the seeds were locally collected from SHFP. Only 18% of the smallholders were able to buy seeds from the seed suppliers and market but at a high price.



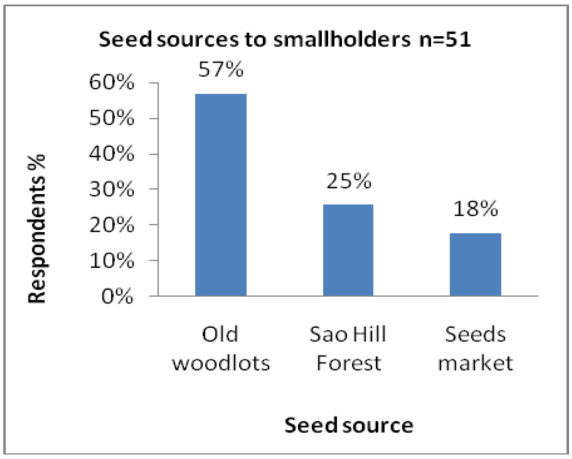


Figure 3: The sources of seedlings and seeds to smallholders woodlots in Mufindi district, Tanzania.

Site Preparation, Pitting, and Planting

Site Preparation

This study found out that 18% of smallholders didn't make any site preparation for planting as indicated in Figure 4. About 40% of smallholders applied simple bush clearing or slashing while 25% took advantage of planting trees within crops (agroforestry) during woodlot establishment. It was found out that trees integrated with crops can co-exist for about two to four years depending on the soil fertility and the crown closure. Few respondents (4%) used fire application for the reason that it's cheap and quick albeit often leads to wildfire. However, 13% of smallholders fully cultivated/ploughed their fields as site preparation for tree planting.*Pitting and Pit Filling*

Pitting was not an issue to care for among smallholders in Mufindi as most of them were not aware of what exact dimensions are suitable for a tree pit. The majority about 81% (Figure 5) reported digging pits of around one-foot (equivalent to 30 cm) depth for planting seedlings. Results indicated that 60% of smallholders infilled pits by taking back the soil to the level of the ground surface without any special consideration as for field crops. About 21% of respondents filled the topsoil from the pit first before the subsoil. However, 13% of respondents filled pits by pressing the soil after filling to keep the seedling firm to the soil and to keep the soil moisture by restricting the excessive water evaporation from the disturbed soil. Moreover, 5% of smallholders filled the soil to the above-ground surface to prevent water retention around the seedling which can cause the death of the young tree.

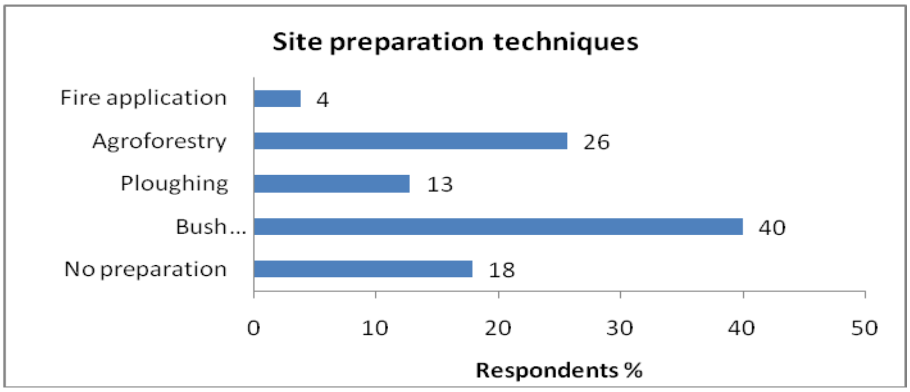


Figure 4: Site preparation technique of smallholders in Mufindi district, Tanzania.

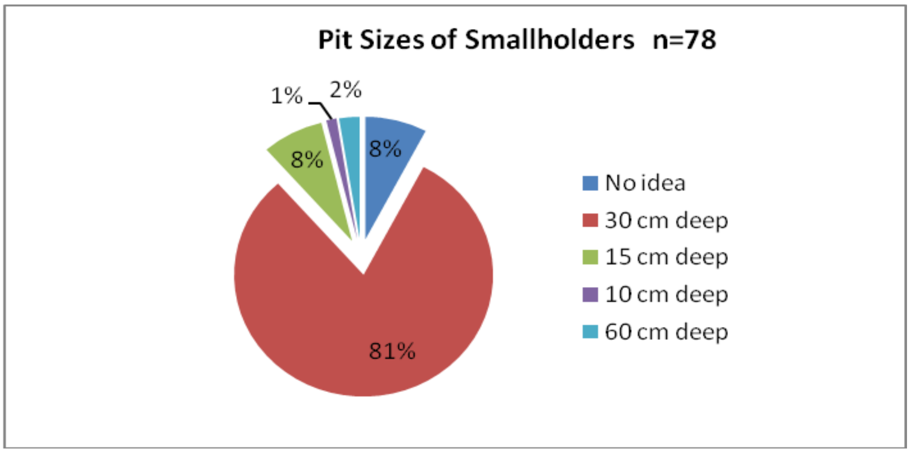


Figure 5: Pit sizes and filling styles for smallholders in Mufindi district, Tanzania.

Planting Space

This study found out that smallholders have varying understanding and opinions on the planting space ranging from 1.5 x 1.5 m, 2 x 2 m, 2.5 x 2.5 m, 3 x 2 m, and 3 x 2.5 m to 3 x 3 m (Figure 6). It was observed that spacing for smallholders varies with different species. However, there're many contradictions among smallholders about the right spacing for both *P. patula* and *E. grandis*. About 83% of smallholders reported using a spacing of 3 x 3 m for *P. patula* while 37% used the same spacing for *E. grandis* thus making the most favourable spacing during woodlots establishment. Smallholders reported using such spacing based on SHFP experience.

E. grandis was found to have many different spacing scenarios among smallholders than *P. patula* which was mostly planted at 3 x 3 m. About 39% of respondents reported planting *E. grandis* at 2 x 2 m while 16% do plant at 2.5 x 2.5 m apart. Generally, smallholders had no clear knowledge of what are the factors to consider for initial spacing.

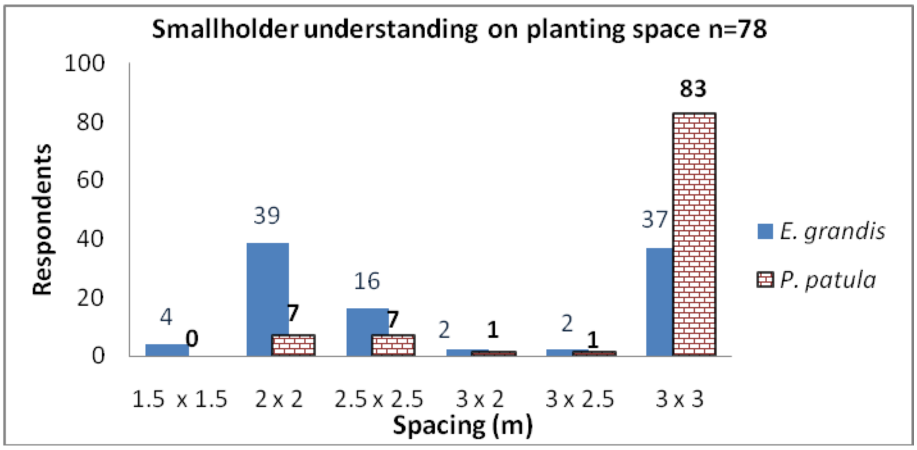


Figure 6: Different planting spaces of smallholders in Mufindi district, Tanzania.

Fertilizer Application

Regarding fertilizer application, the results showed that in very rare cases Mufindi smallholders apply fertilizer to woodlots. Only 2 smallholders out of 78 interviewed smallholders applied fertilizer to their woodlots. Fertilizers applied were Nitrogen, Phosphorus, and Potassium (NPK), and Triple Superphosphate (TSP) soon after planting. The two smallholders own *E.*

grandis woodlots and reported applying fertilizer about 20-30 grammes per tree. However, 40% of smallholders had an understanding of fertilizer to improve the early growth of trees but failed to apply fertilizer because of the limited capital (Table 1).

Woodlot Tending

Weeding Treatment

Results revealed that weeding treatment in smallholder woodlots is a common practice. Few smallholders (15%) reported having never done any weeding for tending their woodlots (Table 2).

Table 1: Failure for fertilizer application among smallholders in Mufindi district, Tanzania.

Reasons for failure to apply fertilizer	Frequency	Percentage
Lack of knowledge on tree fertilizer	23	30
No need for fertilizer in trees	23	30
Limited capital for fertilizer application	30	40
Total	76	100

Table 2: Tending treatments of smallholders in Mufindi district, Tanzania.

Treatments	Types	Time (Years)	Intensity	Instrument	Percentage	Remarks
Weeding	Sanitary slashing	Annually	All trees	Slasher	78	Stop after canopy closure
	Spot weeding	Annually	All trees	Hand hoe	6	
	No weeding	-	-	-	15	
	Total				100	
*Pruning	First pruning only	1.5 - 6	1.6 ± 0.63 m	Machete	19	
	1st and 2nd pruning	3 - 10	2.9 ± 0.87 m	Machete	64	
	1st, 2nd & High pruning	7 - 10	4.5 ± 0.96 m	Machete Ladder	5	High pruning challenge
	No pruning	-	-	-	12	
	Total				100	
Thinning	Low thinning	1.5 – 7	Not fixed	Machete	15	Thin to waste & commercial
	Crown thinning	3 - 12	Not fixed	Chainsaw	12	Commercial thinning
	No thinning	-	-	-	73	
	Total				100	

*Pruning intensity = mean ± standard deviation

About 85% of smallholders in Mufindi had an understanding and reported to practice weeding in their woodlots. The study found out that only two types of weeding exist among interviewed smallholders; sanitary slashing and spot weeding with 78% and 7% of respondents respectively. Smallholders pointed out to prefer sanitary slashing to other weeding types because it's simple and easy to apply.

Pruning Treatment

From Table 2, about 64% of smallholders understand and practice the first and second pruning to their woodlots. About 19% of smallholders practice only first pruning while 5% practice all three pruning regimes. However, 12% of smallholders reported not to practice any pruning treatment to their woodlots. The study found out that 50% of smallholders owning *E. grandis* reported pruning their woodlots especially in case of persistant branches due to whide spacing while all (100%) smallholders owning *P. patula* woodlots reported practising pruning treatment to their woodlots (Table 3). The study revealed a big variation in the understanding of pruning regimes and intensities from one smallholder to another.

The study found out that smallholders prune trees by counting the number of whorls at a specific age rather than using the height knowledge to estimate the pruning height. Referring to Table 2, smallholders reported to do first pruning at the age of 1.5 – 6 years (height of 1.6 ± 0.63 m from the ground); second pruning at 3 - 10 years (height of 2.9 ± 0.87 m); high pruning at 7 - 10 years (height of 4.5 ± 1.91 m). Only 4 smallholders had an understanding of higher pruning. All pruning treatments were done by using machetes which negatively affect the pruning quality.

Thinning Treatment

The results indicated that 73% of smallholders do not thin their woodlots completely while only 27% had an understanding of thinning treatment and sometimes thinned their woodlots. All smallholders had no clear idea about the thinning intensity for their woodlots. However, 15% of these smallholder practices thin to waste, and 12% practice a commercialised thinning (Table 2). About 35% of those who do not thin their woodlots reported that there is no need to do thinning while 32% pointed that a reasonable spacing during planting provides enough space for trees to grow thus thinning is insignificant (Table 4). About 23% of smallholders didn't thin because they had no idea about this treatment while 11% had different reasons such as trees being very scattered in the woodlots due to high mortality after planting. The absence of a market for thinnings and the doubt on how economical thinning is to their woodlots were mentioned. The market for such a commercialized thinning was a village market for firewood, small construction poles, and transmission poles. Moreover, this study found out that smallholders practice two types of thinning i.e., low thinning (thin from below) for *P. patula* and crown thinning (thin from above) for *E. grandis*.

Table 3: Pruning treatment per species of smallholders in Mufindi district, TanzaniaSpecies.

	Number of respondents	Pruning		Not Pruning	
		Frequency	Percentage	Frequency	Percentage
Pinus patula	60	60	100	0	0
Eucalyptus grandis	18	9	50	9	50
Total	78	69	88	9	12

Table 4: Reasons why smallholders do not practice thinning treatment in Mufindi district, Tanzania.

Reason to not thin	Frequency	Percentage
No need	20	35
Reasonable planting space	18	32
Scattered trees	3	5
It is not economical	2	4
No market for thinnings	1	2
No idea	13	23
Total	57	100

Tree Harvesting

Harvesting Rotation

Nearly half of smallholders (Figure 7) would like to harvest their woodlots at the age between 11 - 15 years. Most of the smallholders in this group owned *P. patula* woodlots for sawn timber production. About 33% of smallholders reported harvesting trees in the age range between 5 - 10 years for poles production. However, 18% of respondents reported willingly harvest their woodlots at an age beyond 15 years. These figures represent smallholder willingness to harvest but most of them confirmed to often harvest trees for sawn timber from P. *patula* and *E. grandis* at the age of 8 - 13 years and trees for transmission poles from *E. grandis* at the age of 6 - 8 years.

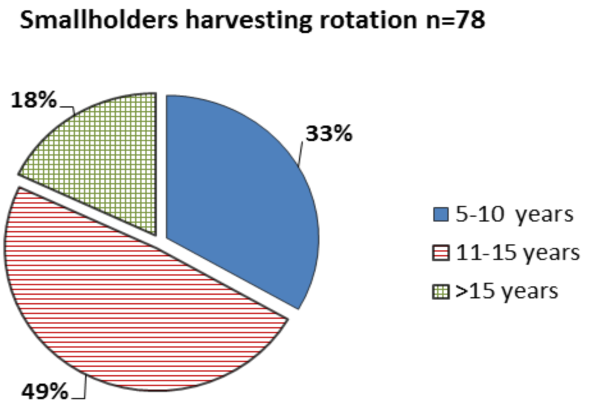


Figure 7: Smallholders harvesting preference in Mufindi district, Tanzania.

The main drive behind early harvest (before 10 years) was mentioned to be the need for money to support household needs such as schooling. Moreover, fear of fire events to woodlots was pointed as well to influence the early harvest. The late harvest of beyond 10 years was perceived by smallholders that trees at that age are matured enough to produce high-quality timber thus trees are sold at a good price. Generally, smallholders in the Mufindi district did not know the optimum rotation age for these two species.

Harvesting System

Results revealed that 85% of smallholders in Mufindi prefer clear-fell harvesting system to their woodlots while only 15% applied selective harvesting system. The main drive for the clear-fell system was acquiring bulky money for satisfying family mega-needs like building houses. Also, that this system supports the easy establishment of the next rotation forest and alternatively supports the land-use change into cropland. Selective harvesting was applied to *E. grandis* involving the selection of trees for fitting to the target market qualities such as transmission and construction poles. Generally, smallholders had no understanding of at what age trees reach full maturity with maximum output as well as the limited knowledge on harvest planning.

Woodlots Silvicultural Assessment

Initial Spacing

The results from the woodlot assessment (Table 5) indicate that about 42% of *P. patula* woodlots had a spacing of 2.5 x 2.5 m followed by 3 x 3 m with 28%. The discussion with smallholders found that they aim to plant *P. patula* at 3 x 3 m apart but the distance measurement during pitting is often done by foot-step counts thus cannot result in 3 m precisely. The most probability was to make less than 3 m because of the short walk steps, the hilly terrain, and the grassy fields thus difficult to make one-meter foot-steps. Spacing for *E. grandis* was found to be similar to that of *P. patula* except that *E. grandis* had an additional shorter spacing of 1.5 x 1.5 m (Table 5). Despite many smallholders reporting to plant *E. grandis* at the same spacing as *P. patula*, results indicated that spacing of 2 x 2, 2.5 x 2.5, and 3 x 3 m occupied a similar percentage of *E. grandis* woodlots of about 22%. Spacing for *E. grandis* had a big variation between smallholder woodlots.

Table 5: Trees spacing in smallholder woodlots of both *P. patula* and *E. grandis* in Mufindi district, Tanzania.

Pinus patula			*Eucalyptus grandis*		
Spacing (m)	**Frequency**	**Percentage**	**Spacing (m)**	**Frequency**	**Percentage**
2 x 2	7	11	1.5 x 1.5	1	6
2.5 x 2	1	2	2 x 2	4	22
2.5 x 2.5	25	42	2.5 x 2	1	6
3 x 2.5	10	17	2.5 x 2.5	4	22
3 x 3	17	28	3 x 2	2	11
			3 x 2.5	2	11
			3 x 3	4	22
Total	60	100	Total	18	100

Weeding Intensity

Regarding weeding intensity, results revealed that 12% of smallholder woodlots were without any weeding while 40% were poorly weeded with a lot of shrubs and grasses (Figure 8). About 33% of woodlots experienced moderate weeding meaning that woodlots had no shrubs but had tall grasses underneath trees. Only 15% of woodlots experienced intensive weeding whereby farms were completely clean.

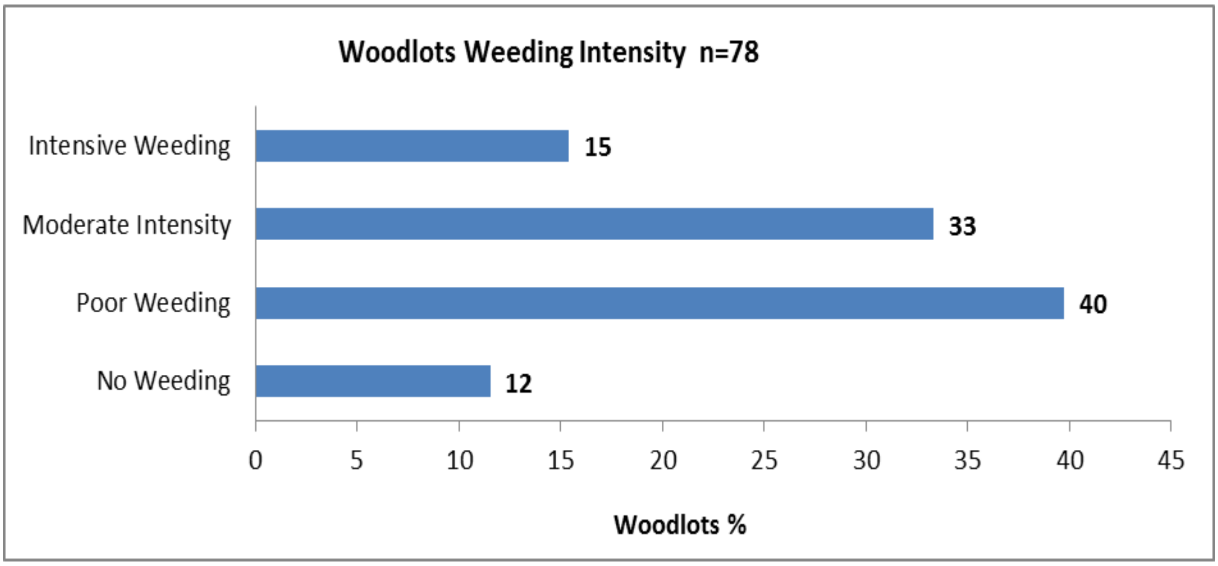


Figure 8: Weeding intensities in smallholder woodlots of Mufindi district, Tanzania.

Pruning Intensity

The results from the woodlots assessment revealed that 53% of smallholder woodlots had a pruned bole from the ground to about 2 m high from the ground (Table 6). About 14% of woodlots were pruned to 1 m high while 8% and 6% were pruned to 3 m and 4 m high respectively. However, 19% of smallholder woodlots were not pruned completely whereby 78% of *E. grandis* were not pruned as well as 2% of *P. patula*. The pruning intensity was highly affected by the fact that smallholders use a normal machete for pruning hence finds it difficult to prune beyond 2 m. By the use of ladders, few managed to prune at higher heights of 3 and 4 m.

Table 6: Pruning intensity of smallholder woodlots in Mufindi district, Tanzania.

Pruning intensity	*P. patula*		*E. grandis*		Both species	
	Frequency	Percentage	Frequency	Percentage	Frequency	Percentage
1 m	9	15	2	11	11	14
2 m	39	65	2	11	41	53
3 m	6	10	0	0	6	8
4 m	5	8	0	0	5	6
No Pruning	1	2	14	78	15	19
Total	60	100	18	100	78	100

Pruning Quality and Stem Form

A total of 2429 trees were assessed in 60 *P. patula* woodlots while 892 trees were assessed in 18 *E. grandis* woodlots for pruning qualities. Results (Table 7) revealed that all *P. patula* trees were once pruned while only 71 trees of *E. grandis* experienced this treatment. For *P. patula*, 89% of trees were properly pruned but 7% of trees had branch stabs left on stems while 4% of stems experienced bark peeling due to poor pruning techniques. About 70% of the pruned *E. grandis* stems were properly pruned while the remaining 10% had branch stabs left around the stem. Except for some rare cases of abnormal, a good number of smallholders do not prune *E. grandis* because they understand that is a self-pruning species.

Table 7: Pruning qualities and stem forms of trees in smallholder woodlots in Mufindi district, Tanzania.

Features	Condition	*Pinus patula*		*Eucalyptus grandis*	
		Frequency	Percentage	Frequency	Percentage
Pruning quality	Properly Pruned	2154	89	64	90
	Branch stabs left	182	7	7	10
	Bark removed	93	4	0	0
	Total	2429	100	71	100
Stem form	Straight	2046	84	724	81
	Slight bent	314	13	112	13
	Crooked	69	3	56	6
	Total	2429	100	892	100
Other conditions	Forked	170	7	64	7
	Suppressed	116	4	20	2

Note:
Slight bent = A tree with a bending stem due to different factors like early tree forking, soil creep, wind effect, etc.
Crooked stem = A deformed tree with a twisted stem often with more than one sweep resulting in a reaction wood.

Stem Form and Quality

About 84% of trees in *P. patula* woodlots had a straight stem while 13% had slight bent stems mostly due to bi-forked stems and 3% of trees had a crooked stem (Table 7). *E. grandis* trees had 81% of straight stems, 13% of slightly bent stems while crooked stems were 6% of all trees. During the assessment, there were encounters of different unpleasant stems conditions as a result of poor silvicultural treatments. For instance, *P. patula* had about 170 (7%) forked stems while *E. grandis* had 64 (7%) forked stems. Some stems were weak and suppressed as a result of delayed beating-up thus trees grow under the shade of others causing their failure to compete for light and nutrients.

Thinning Condition

The study found out that 83% of smallholder woodlots were not thinned as indicated in Figure 9. The remaining 17% of these woodlots had been thinned once or twice. Most of these thinned woodlots experienced either thin to waste especially for *P. patula* or commercial thinning for *E. grandis*. Thin to waste was highly discouraged while thinning from below system was supported whereby weak and suppressed trees are thinned in the *P. patula* woodlots. Thinning from *E. grandis* can be marketed as poles in a timber market. However, during the study, it was observed that lack of planning for the extraction of thinnings made this treatment difficult with huge damage to the remaining trees.

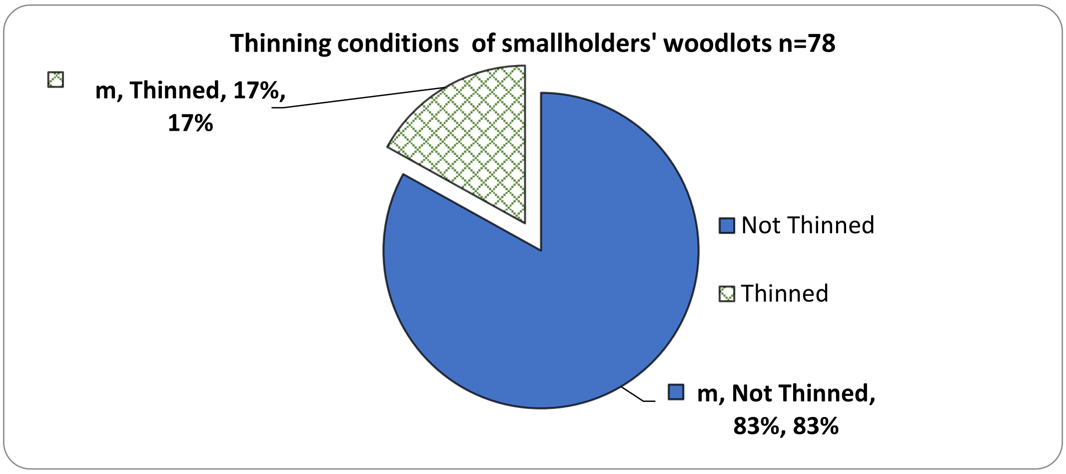


Figure 9: Thinning conditions of smallholder woodlots in Mufindi district, Tanzania.

Harvesting Condition

Some harvesting silvicultural factors like stump quality, harvesting impacts, and coppices condition were assessed during this study. Many thinned and formerly harvested woodlots had stumps in a good condition which can support coppice development for *E. grandis*. In most cases, negative impacts like damage to the remaining trees caused by harvesting activities were observed. Moreover, coppicing stumps well-sprouted in woodlots even though the coppices were not managed but left to freely grow around the stumps. Only two woodlots had well-managed coppices through a singling system to give space for fewer but robust coppices to grow. Coppice management was a contradicting practice to smallholders in the Mufindi district.

DISCUSSION

Silvicultural Knowledge and Sources

Silvicultural knowledge for proper woodlots management among smallholders is an important factor to enhance the good performance of their woodlots and maximize the output for a better rural economy. Smallholders in Mufindi have a certain understanding of plantation trees management as a result of a long-time experience from neighbours and SHFP. Similar results were found by Mpiluka (2016) that 55.6% of smallholders of studied villages in Mufindi district adapted silvicultural treatments from neighbours while 44.4% adapted from SHFP. Many smallholders had a chance to either live near this big plantation or being neighbours to plantation workers or had a chance to temporary work in the enterprise thus the diffusion of the knowledge. Moreover, being involved in different tree planting and management programmes; communities are influenced to engage in small-scale plantations (FAO 2017, Mpiluka 2016).

The missing knowledge on further silvicultural operations is caused by the fact that these operations such as thinning is also done to a limited scale at SHFP and so do not involve a large number of casual labourers hence the knowledge limitation to communities around. Still, there is a big variation and contradicting opinion among smallholders on some of the treatments, their application, and their effects on the woodlots. These confusions are the outcome of free forestry technical knowledge diffusion to smallholders without the aid of experts. The clear knowledge of what is the right time and required intensity of different treatments is still missing among smallholders.

Indirectly, limited extension services to smallholders influence contradiction among smallholders even for common treatments like initial spacing and pruning. However, smallholders with access to extension services have expressed much concern and care for woodlot farming. This commitment goes deep into their passion to buy improved seeds at expensive prices for better woodlot performance and yield. Many farmers lack clear prior planning of their forestry activities thus fail to implement all important treatments as required. Also, the sustainability of these services is questionable because extension services offered on a programme basis are highly dependent on donor funds. Through this study, it's clear that extension is needed for smallholders and that there are all favourable environments to make this possible and sustainable. For instance, nearly all of the smallholders can read and write hence there is no illiteracy challenge. This indicates that smallholders can easily acquire extension knowledge with moderate but sustainable supervision (Antwi-Agyei and Stringer 2021, Anyonge and Roshetko 2003).

Forestry-related associations existing among smallholders are good means to ease the delivery and monitoring of silvicultural knowledge. For example, with the support from some NGOs and programmes, smallholders in some villages have been encouraged to formulate and formalise Tree Growers Associations (TGAs). Until May 2019, PFP had successfully influenced and supported about 30 TGAs in the Mufindi district thus there is room for more initiatives by the government and other NGOs to support the remaining smallholders in groups. However, a limited number of associations and poor participation of smallholders can be challenging to extension services. Best extension services to smallholders often target to create the knowledge system whose capacity building activities are for a long time enough to ensure the demonstration effects are created in a sustainable way (Antwi-Agyei and Stringer 2021, Arvola *et al.* 2019, FAO *et al.* 2014). Generally, the study proves that smallholders in the Mufindi district have a certain understating of silvicultural treatment at different levels albeit it's a question of how smallholders apply this knowledge to manage woodlots (Beltrán 2019).

Tree Species Selection

Species selection is among the essential aspects of silviculture because selected species must be compatible with different growth aspects like site quality, weather, altitude, and other ecological aspects. The adaptability of tree species to a particular environment and market must be taken into account before a plantation/woodlot establishment (Nigussie *et al.* 2021). Smallholders pointed out that the long-time stability of *P. patula* to the good market price had been so impressive even though the current market allocate a high price for Eucalyptus tree than Pine tree thus a gradual preference shift. Further, Eucalyptus can be harvested at a much shorter rotation. The alternating demand and price fluctuation of these species is a challenge to smallholders concerning species choice.

Seeds and Seedling Sources

One of the big challenges facing smallholder forestry in Mufindi is a limited understanding and availability of high-quality seeds/seedlings to support the better performance of woodlots. Seeds are locally collected from genetically poor mother trees hence affect their germination percentage as well as result in poor tree qualities. In this study, more than 80% of smallholder woodlots were established from locally raised seedlings, the majority from genetically weak seed sources. A similar scenario of unimproved and locally collected seeds is dominating other southern highlands smallholder woodlots as shown in the findings by Held *et al.* (2017). However, woodlot yield maximization can be attained when proper silvicultural treatments are applied to the right tree species from a good seed source. Except for few smallholders who benefited from the improved seedling donation by the government and NGOs, trees in smallholder woodlots are affected by poor stem qualities (see Table 7). Qualities like crooked stems, forked trees, and the big variation of diameters among trees of the same age are partly influenced by low-quality seeds connected to inbred sources (Chamshama *et al.* 2009, Nef *et al.* 2021).

Site Preparation, Pitting, and Planting

Site Preparation

The knowledge of site preparation as applied to the farming of food crops is well known among smallholders although not often practised for tree planting sites. Sometimes smallholders establish woodlots within crops field accounting as an alternative to site preparation. Despite the understanding, a big number of smallholders plant trees within tall grasses with very little preparation like bush clearing as also shown by Beltrá (2019). Limited time and capital to hire labour force were often pointed for the failure to practice intensive site preparation. With wrong perceptions, some smallholders report that there is no need to make intensive preparation for the grasslands because it has a little negative effect on new trees. FDT (2016a) confirmed a retarded growth and low survival percentage for trees growing within the unprepared farm with strong weed competition.

Vigorous growth of a seedling soon after planting is partly influenced by the nature of site preparation. Preparation has an impact on the primary roots extension and nutrient competition of seedlings with other plants. In this way, a site without any preparation likely results in poor performance of trees while an intensive preparation like ploughing promotes robust tree growth thus the good performance. For instance, ploughing as an intensive site preparation technique tripled the volume of 6 years *P. patula* at SHFP in Tanzania (Chamshama 2014). Many woodlots of smallholders might face poor early growth and performance as a result of poor site preparation.

Pitting and Pit Filling

Pit depth and diameter play a great role in a tree's early growth because poor pitting techniques can result in poor survival and growth. In most cases, pit sizes of 30 cm deep x 30 cm diameter are used in Tanzania plantations in normal sites. But in special sites like arid areas, larger sizes (40 cm depth and diameter) are recommended (Chamshama 2014). Moreover, pit filling after putting a seedling influences the development of primary roots and consequently determines the survival of trees. However, the majority of smallholders lack knowledge of the exact pit sizes and their influence on woodlot performance. As a result of this knowledge gap, many carelessly fill back the soil without any special consideration. Smallholders are supposed to consider the pitting 20 - 30 cm deep x 20 - 30 cm wide in their woodlots as recommended in the Forest Plantation and Woodlot Technical Guidelines (FBD 2021). Topsoil rich in humus should come first in the pit to supply the organic nutrients to the fresh roots then the remaining subsoil is mildly firmed around the roots to enhance the earth into close contact with the roots. Gentle firming of filled soil ensures intimate contact of roots and soil for moisture and nutrient absorption.

Planting Space

Initial spacing during woodlot establishment is of importance to determine stem volume and quality. Different spacing have been adapted and recommended by different scholars. For instance, spacing of 2.5 x 2.5 m with thinning at the age of 6 – 8 years or spacing of 3.5 x 3.5 m without thinning has been suggested in the guidelines for Makete district smallholder farmers by Malimbwi *et al.* (2010). The majority of smallholders use the initial spacing of 3 x 3 m for both *P. patula* and *E. grandis* even though there are some contradictions among smallholders about the right spacing. But, Technical Order No. 1 of 2021 has recommended initial spacing of 3 x 3 for sawn logs and 2 x 2 for poles and pulpwood production (FBD 2021). The knowledge from Technical Order is essential to clear smallholders' contradiction because initial spacing determines stocking thus directly influence tree diameter and woodlot performance then dictates further silvicultural treatments. Assessment of woodlots proved that trees spacing is not regular and consistent because of the use of foot-step counts during pitting for planting. Due to this, more than 50% of woodlots bear tree spacing less than 3 m and some scattered open gaps due to high mortality (see Table 5). These irregular spacings and mortality gaps have negatively affected smallholder woodlot stocking, tree diameter distribution, stem forms/qualities. Due to poor stocking, there is no correlation between land sizes set for woodlot investment to the actual number of stems managed in a woodlot. Many smallholders don't thin but their woodlots have a very low density thus trees can't efficiently utilize all the available space hence bushes, thorns, and weeds occupying gaps.

Fertilizer Application

There is a positive correlation between fertilizer application and trees growth most observed during the first year after planting. Tanzania plantations often use NPK fertilizer of about 30 g for every single planted seedling (FDT 2016b). Through this study, it's clear that fertilizer application to woodlots is not common among Mufindi smallholders whereby less than 5% apply fertilizer to their woodlots. Two types of fertilizers applied to woodlots soon after planting are NPK and TSP. The knowledge on fertilizer application is less available to smallholders while some reported that there is no need for fertilizer use for trees to grow well. Other (30%) smallholders declared to have no idea on fertilizer application to woodlots because they often understand that fertilizer application is for food crops and tea plots. While studies confirm that species like E. *grandis* responds better with fertilizer right after planting. For instance, 30 g per seedling at 20 cm from the seedling collar has been used by PFP (2016) in Tree Growing Incentive Scheme Guidelines.

Woodlot Tending

Weeding Treatment

Weeding regimes and intensities influence the early growth of trees in woodlots (Silva *et al.* 2012). Ranging from sanitary slashing to complete weeding, weeding may determine the survival percentage, the stem form, tree health, and the increment. Generally, it's known that weeds compete with a tree on the limited light, water, and nutrients resources in the woodlot thus negatively affecting the tree growth (Deng *et al.* 2020). For instance, a 2.5 year *P. patula* attained a height of 4.6 m, Dbh of 5.4 cm, and survival of 88% under complete weeding while a retarded height of 1.7 m, Dbh of 1.7 cm, and survival of 80% without any weeding were observed in FDT trial plots in Mufindi district. Moreover, weeds and other vegetation in the woodlot increase the risk of fire events as well as accommodate destructive animals like rats that are likely to eat planted seedlings (Chamshama 2014, FDT 2016b).

More than three-quarters of smallholders in Mufindi understand and practice weeding of different intensities to their woodlots. However, the woodlots assessment proved that near half of the woodlots experienced poor weeding (see Table 2 & Figure 8). Rarely, smallholders practice complete weeding especially when intercropping with food crops is used but most of the smallholders apply sanitary slashing and few spot weeding. Due to different reasons like limited time, smallholders don't practice weeding of the young woodlots every season as required. This has negatively affected the survival and growth of young trees in their woodlots.

Pruning Treatment

Whenever a knot-free timber is desired, some species need a manual severance of branches of trees at a certain age. On the other hand, access pruning to woodlots helps in fire fighting by restricting the outbreak of crown fires from surface fire (Chamshama 2014). Smallholders understand and prune their woodlots at different stages although first pruning is often done by a big number of them. Averagely, at the age of 3.5 years the first pruning and age of 6.5 years the second pruning is done by smallholders. The average pruning intensity for first pruning is 1.6 ± 0.63 m while second pruning has an average intensity of 2.9 ± 0.87 m. The pruning age is almost similar to that of Technical Order No. 1 of 2021 whereby the first pruning of *P. patula* for the site class II is 3.5 years and second pruning is 5.5 years. However, pruning height of smallholders has a big variation between woodlots and is shorter compared to that of Technical Order where pruning height of 2.4 m and 4.6 m is recommended for first and second pruning respectively (FBD 2021). In this case, a big percentage of pruning intensities can't afford to produce a 3.7 m (12 ft) clean bole as per minimum log length requirements for sawn timber (Tables 2 & 6).

Smallholders have a limited pruning technology as they all use machetes to prune trees thus affecting the pruning quality. Tree damages like bark peeling and stabs left after pruning can be observed in smallholder woodlots (Table 7). Apart from poor technology, most of these damages are the consequence of poor silviculture skills of both smallholders and labourers thus producing low-quality timber (Arvola *et al.* 2019). A big variation of the pruning regimes among smallholders confirms the knowledge gap that has to be alleviated through extension services for smallholders to adapt to the most effective pruning regimes.

Thinning Treatment

Being tied to the initial spacing and target end product, thinning is one of the silvicultural treatments in plantation forestry. It opens up more space for crown and root development to enhance/support stem diameter increment. Nevertheless, it can provide intermediate returns before the final harvest whenever commercial thinning is applied. However, for a better outcome, thinning has to be done at the right time and with the right intensity otherwise can negatively affect the stand volume (Evans and Turnbull 2004, Chamshama 2011). A good number of smallholders lack a clear understanding of thinning treatment and its implication to the woodlot performance thus do not practise thinning. Due to limited knowledge, there are variations in the thinning regimes among smallholders who apply this treatment. Some reported starting thinning of *P. patula* at the age of 1.5 years while others do thin the same species at the age of 12 years (Table 2).

Whether thinning to waste or commercialized thinning, proper thinning regimes have to be followed. For sawn-timber production, *P. patula* initially spaced at 3 m x 3 m is thinned at the age 10 and 15 years as per Technical Order No. 1 (2003) used by SHFP and GRL in Mufindi district (Akyoo, 2017). The challenge is the market for *P. patula* thinning being very rare while that of *E. grandis* is available for fuel-wood and small construction poles. Moreover, when not properly planned and implemented, thinning operations have led to huge damage to the remaining trees in woodlots as observed during this study. To reduce costs and avoid damages to the remaining trees, smallholders adopt a wide spacing of about 3 x 3 m then skip thinning treatment of *P. patula*.

Tree Harvesting

Technical Order No. 1 of 2021 has recommended a rotation age of 18 years for sawn timber production from both *P. patula* and *E. grandis* while 7 years has been recommended for pulp wood and transmission poles production. The proposed rotation is based on the growth data of SHFP in the Mufindi district for site class II because most of the compartments fall within this site class. At that age *P. patula* produces a maximum stand value for timber production (FBD 2021, Laswai *et al.* 2018). Without any financial pressure, smallholders in Mufindi declared a willingness to harvest woodlots for sawn timber between 11 - 15 years without any intermediate intervention i.e., through a clear-fell harvesting system (Figure 7). However, most of them harvest woodlots before 10 years to solve financial challenges. This is similar to the results in the study by Malimbwi *et al.* (2010) in Makete district which showed that smallholders harvest premature woodlots at the age of 8 years to solve financial problems. Transmission poles from *E. grandis* are commonly harvested at the age of 6 - 8 years with more than one intervention (selective harvesting). So, the rotation age for smallholder woodlots is mostly influenced by the family need for money to handle financial problems. Due to this, sometimes smallholders sell very young stands with the age of 4 years at a very cheap price. The innovation of alternative sources of income can reduce a level of dependence on woodlots thus influence the late harvest at maturity (Malimbwi *et al.* 2010).

The study by Francis (2012) reported that there is a very small increase in market timber prices as trees grow larger thus it is insignificant for smallholders to wait longer for timber harvest. The particular study recommended smallholders to use 8 - 12 years rotations harvest that it's more profitable to harvest younger woodlots. That proposed rotations contradict the current Technical Order for plantations where a rotation of 18 years is recommended (FBD 2021). Moreover, harvesting juvenile trees below the recommended rotation by the Technical Order is not suitable for structural timber as can cause structures/buildings to collapse. Based on this study, the timber market is very sensitive to tree diameter at harvest and is willing to offer good prices for big trees. Big diameter and matured trees are very scarce in the market because only state forests can supply such valuable timber at the moment. Based on facts from this study, smallholders are encouraged to use 18 years rotation for sawn timber whenever possible as directed by FBD (2021). This can ensure a supply of matured timber in the market and provide a good return to smallholders.

Challenges Facing Smallholders Silviculture

Smallholder forestry in many developing countries is unstable and less attention had been paid to this sector. Due to this, many challenges had been facing smallholder woodlots management. The biggest challenge to smallholder forestry is inadequate technical knowledge on proper silvicultural treatments which can maximize the performance of woodlots while meeting the market demand. For instance, it was found out that smallholders have no idea on how to identify potential mother trees for genetically sound seeds collection in their matured woodlots. Apart from that, the availability of improved seeds to smallholders is a long-time challenge while whenever available have been marketed at an unaffordable price to smallholders (Arvola *et al.* 2019).

Moreover, smallholders have been experiencing limited income sources which hinder them to practice the basic knowledge or experience they have on silvicultural treatments. It's hard for smallholders who depend on family labour to hire extra labour force for woodlot works whenever needed thus sometimes skip some important treatments like weeding (Baker *et al.* 2017). This has affected the trees' survival and influenced the development of trees with poor stem forms like tapered trees due to early strong branches because of the skipped pruning. Also, poor technology had been a challenge to smallholders in the Mufindi district. For example, they do pruning by using a machete which often damages tree stems by causing big wounds instead of using pruning saws as recommended. Poor thinning/harvesting technology often causes damages to remaining trees in smallholder woodlots (Held *et al.* 2017).

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

Generally, smallholders have a primary understanding of different silvicultural treatments as gained from big forest enterprises and fellow farmers. However, their understanding of most of the treatments is varying from one smallholder to another. Their desire to invest in the best woodlots management practices is hindered by the lack of concrete technical skills such as intensities for different treatments. Extension services are inadequate in such a way that farmers can't access technical knowledge at the village level. So, the knowledge gap to be addressed should be the direct practical skills at the farm level to impact smallholder planning and implementation of different treatments. Smallholders require skills to prior plan for woodlot establishment and its corresponding treatments fitting to a particular end product.

As influenced by the market demand and prices fluctuations, smallholder plant both *P. patula* and *E. grandis* while *P. patula* is the most dominating species in the woodlots. However, these woodlots are established through seedlings raised in local nurseries whereby seeds for seedlings are locally collected from old woodlots. Furthermore, the quality of treatments in smallholder woodlots including site preparation and pitting for planting is poor and inconsistent. Most of the woodlots are either over-stocked or under-stocked with irregular spacing between trees due to the lack of technical skills on initial spacing. Trees are growing within shrubs and dense weeds affecting the stem qualities and woodlot performance. Poor pruning techniques and the use of machete for pruning have left some trees with stubs and peeled stems thus destroying wood qualities. Furthermore, the knowledge gap on thinning and uncertain market for thinnings affected this treatment to smallholder woodlots. Also, smallholders harvest young trees below the recommended rotation age by the Technical Order thus filling the market with juvenile timber. With many challenges, the silvicultural treatments and general quality of woodlots is not good thus needs to be addressed to ensure the supply of quality timber.

Recommendations

As it's for other agricultural crops, this study recommends forest extension officers to work at the ward/village level in the region contrary to how it is now that forest officers are accessible at the district level and are few and do not have resources to visit tree growers. Alternatively, as an interim measure, agricultural extension officers who are already at these levels be trained on forestry aspects and assist with extension. This will bring practical knowledge and skills to smallholders and help to sustainably and closely solve many silvicultural challenges. The education and capacity building should as well address to smallholders on quality timber farming to meet the good qualities through demonstration plots. Also, smallholders in every village should be freely organized into associations (TGAs) and linked to different services. These TGAs should be networked and well monitored to come up with the best positive effects on smallholder forestry.

Moreover, its important smallholders get introduced to more marketable coniferous species other than *P. patula* because any massive pest and diseases outbreak can lead to a terrible disaster to their economy as well as to the timber industry. Also, to improve the performance and quality of woodlots, the government should provide seeds subsidies for smallholders as it is for agricultural crops. This will encourage smallholders to use improved seeds in their nurseries. As recommended in the Technical Orders 01 of 2021, smallholders should adopt intensive preparation like ploughing while pit sizes of 20 - 30 cm deep x 20 - 30 cm diameter are encouraged to support the survival and early growth of trees. The study recommends initial spacing of 3 x 3 m for sawn logs and 2 x 2 m for poles and pulpwood production. For the weeding operation, this study recommends smallholders adopt complete weeding or strip weeding (0.5 m) on each side of the tree line. However, the integration of food crops with trees (agroforestry) is also recommended because can support the weeding of trees while tending food crops. Moreover, smallholders are encouraged to use pruning saws to reduce damage to trees the good stem qualities. With two thinning interventions, smallholders should harvest trees at 18 years rotation for sawn timber while 7 years are recommended for pulpwood and transmission poles as directed by the Technical Orders 01 of 2021 to ensure a supply of matured timber in the market.

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