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Time Consumption and Productivity of *Sandat* Felling Technique in Private Forests in Probolinggo, Indonesia

Ahmad Budiaman*, Hardjanto, Sarah Agustin, Lawrensia, Yohana Natalia Rahayaan, Chandra Puspita Maharani, Zest Limbong

Department of Forest Management, Faculty of Forestry and Environment, IPB University, Academic Ring Road, Campus IPB Dramaga, Bogor, Indonesia 16680

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Abstract

Agroforestry is a cropping pattern that is commonly applied to private forest management in Indonesia. Agroforestry based private forest is a land-based silviculture that incorporates forestry plants with agricultural crops, plantation crops, and multi-purpose plants. One of the felling techniques used in agroforestry based private forests is the sandat-felling technique (SFT), which is a rope-assist felling technique. The felling technique was used to protect the remaining stand of the agroforestry based private forest. This technique is an innovation in the harvesting of agroforestry based private forests in Indonesia. The time consumption and productivity of this technique are not yet known. This study aims to assess the working time and productivity of SFT in agroforestry based private forests in Probolinggo, East Java, Indonesia. The observed tree-felling technique included rope installation and tree-felling operations. The performance of the SFT was evaluated by analyzing its working time and productivity. The results of the study showed that the total working time of the SFT was 8.65 minutes tree^{-1}, which consisted of 33.34% for rope installation and 66.66% for felling operation. The productivity of the SFT was 2.02 m^3 hour^{-1}.

Keywords: *assisted technology, tree felling innovation, directional felling, remaining forest stand*

**Correspondence author, email*: *budiaman@apps.ipb.ac.id, tel.+62-251-8621677, fax.+62-251-8621256*

Introduction

Private forests play a substantial role in the development of forestry in Indonesia and rural private economies. The economic contribution of private forests to household income ranges from 5.6% to 75.0%. It depends on the site, cropping pattern, and plant type (Hardjanto, 2001; Achmad & Purwanto, 2014). In addition to their production and economic functions, private forests also serve ecological and social functions (Olivi et al., 2015; Laraswati et al., 2020; Kurniawan et al., 2020). In 2014, the production of logs from private forests exceeded that from natural forests. The area of private forests in Indonesia has reached 34.8 million ha, with a potential wood production of approximately 990.7 million m^3 (MoEF, 2015). In Indonesia, private forests have been utilized as sources of food and income inherited from forest farmers (Apriyanto et al., 2016; Sabilla et al., 2017; Lestari et al., 2018). Private forests contribute to land rehabilitation (Kurniawan et al., 2018), water and soil conservation (Murtiono & Wuryanta, 2019), and biodiversity (Soendjoto et al., 2008; Rambey et al., 2021).

In Indonesia, private forests are constructed using three silviculture systems: monoculture, mixed forest, and agroforestry (Herwanti, 2015; Prihatiningtyas et al., 2017; Maharani et al., 2022). The monoculture pattern is a planting system with only 1–2 forestry species, whereas the mixed forest pattern mixes forestry plants with plants other than crops (Hardjanto, 2003; Widiarti & Prajadinata, 2008). Agroforestry based private forests are land-based silvicultures that incorporate forestry plants with other plants, such as multipurpose tree species (MPTS), plantation crops, and crops. Each plant contributes substantially to the prosperity and income of private forest farmers (Diniyati & Achmad, 2015; Arinah et al., 2021; Anjarsari et al., 2022). Therefore, adequate maintenance and protection of forest stands are required for optimal growth and yield. Agroforestry based private forests differ from monoculture and mixed private forests in structure and composition. It possesses multi-story canopy structures and diverse stand compositions (Suryanto & Suryawan, 2015; Siarudin et al., 2017; Zulkarnaen, 2020).

Directional felling is the most suitable felling technique for complex forest stands. Directional felling refers to the practice of felling trees in a predetermined direction to increase the efficiency of wood skidding and prevent damage to residual forest stands (Cedergren et al., 2002; Nikooy et al., 2013). In certain circumstances, such as dense forests or steep terrain, the felling direction cannot be determined solely by using a notch cut, but also requires tree-felling aids. This method is typically referred to as assist-felling direction (Leslie, 2019; Holzfeind et al., 2020).

A wire or hemp rope is commonly used to assist in tree felling so that the tree falls in the desired direction; this includes trees in a hang-up state (Nikooy et al., 2013; Bianchini et al., 2021). Utilizing a hemp rope is less expensive than using a winch, a hydraulic jack, or a wire rope. The use of hemp rope in the assist felling technique has several advantages, including cost savings, increased worker safety, simplicity of installation, light weight, and lower cost than wire rope (Hartter et al., 2006, Purwono & Yatnawijaya, 2013).

The use of hemp ropes to assist in felling trees has been conducted in private forests in some regions of Indonesia. In tree-felling operations, the use of rope has two purposes: a) to direct trees falling in the intended direction (directional felling) and b) to prevent felled trees from directly falling to the ground. Rope as a tool to guide the direction of tree felling is commonly used in private forest harvesting in West Java. This technique is employed simply by pulling the trees to fall directly to the ground (Sukadaryati et al., 2008). When this technique is applied to agroforestry based private forests, it causes additional damage to the remaining stands. The second use of a rope is to prevent the felled trees from falling directly to the ground. This technique is applied in felling operations in agroforestry based private forests in the Probolinggo Regency, East Java, Indonesia. This is an innovative and eco-friendly felling technique. Private forest farmers refer to this technique as the *sandat* forest technique (SFT), which translates to "safety rope technique." It involves directing trees to fall into a stretched rope or a flexible belt, which has been previously installed between two spar trees so that harvested trees do not fall directly to the ground but instead hang up from the stretched rope. Although the *sandat* technique has been implemented since 2009, no information regarding its working time and productivity is available.

A time study is one of the basic analyses used to optimize a production process (Kanawaty, 1992). In felling operations, working time is required to plan, monitor, and evaluate felling operations, determine the remuneration system, optimize employment, and determine the standard time for felling operations (Mujetahid, 2009; Szewczyk & Sowa, 2017). This study aimed to assess the time consumption and productivity of the SFT for an agroforestry based private forest in Probolinggo, East Java, Indonesia.

Methods

Study site This study was conducted in one of the agroforestry based private forests owned by forest farmers in Roto Village, Krucil District, Probolinggo Regency, East Java, Indonesia (Figure 1). The forest was then felled by using a selective cutting system. The forest farmer was a member of the Alas Mandiri Probolinggo private forest cooperative, which is a Kutai Timber Indonesia Forest Company partner. Fifty percent of the study area included

Figure 1 Location of the study, Roto Village, Probolinggo Regency, East Java, Indonesia.

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land with a more than 20° slope. The average rainfall is 2,297 mm year^{-1}. The elevation of the study area ranges from 600–700 m asl and is located in the Pekalen Watershed. The tree species planted in the study area were *sengon* (*Paraserianthes falcataria*), *jabon* (*Anthocepalus cadamba*), *balsa* (*Ochroma* sp.), *waru* (*Hisbicus similis*), *gmelina* (*Gmelina arborea*), *anggrung* (*Trema orientale*), and mahagony (*Swietenia macrophyla*). Other plants, such as gliricidia and elephant grass, were used as terraces, and bamboo, coffee, and other fruit trees were used as protection plants along the riverbank. The planting system was regulated with an optimum spacing of 6 m × 6 m so that the space between plants could be planted with intercrops, such as *porang*, cassava, and banana.

Research procedure This study was conducted in three stages: a) pre-harvesting inventory, b) observation of the SFT, and c) assessment of working time and productivity.

Pre-harvesting inventory The objective of the pre-harvesting inventory was to gather information about the site characteristics of the study area, specifically the stand structure and composition of agroforestry based private forests (Simon, 1996; Dau et al., 2015). A pre-harvesting inventory was conducted prior to private forest harvesting. The sampling technique used was a uniform systematic distribution (Simon, 1996), with the initial plot being determined purposively, starting at an easily accessible location at the study site. The sample plot was a square with dimensions of 10 m × 10 m. This plot size was chosen because the trees to be cut were included in the pole stage (diameter > 10 cm) (Simon, 1996; Herwanti, 2015). The plots were placed at the intersection points between the lanes and lines. The distance between the centers of the plots was 20 m. Twenty-six plots were obtained with an observed area of 0.59 ha. The diameter at breast height (dbh) was measured using a diameter tape. A hypsometer was used to measure the total tree and merchantable heights.

Tree species were classified into four groups: 1) forestry plants, 2) multi-purpose tree species, 3) plantation crops, and 4) agricultural crops. Forestry plants are woody plants that are cultivated to produce logs as raw materials for wood industries, such as sawmills, plywood, and woodworking (Jariyah & Wahyuningrum, 2008; Soendjoto et al., 2008; Yuwono & Hilmanto, 2015). MPTS are woody plants that produce wood and non-timber forest products (fruits, resin, latex, tree bark, and others). Plantation crops are plants grown for long periods of time. The types of plantation crops include cacao, cocos, banana, coffee, and rubber (Iswandi et al., 1996; Widiarti & Prajadinata, 2008; Sanudin & Fauziah, 2015). Agricultural crops are cultivated to produce food, animal feed, or for other economic purposes (Achmad & Purwanto 2014; Hisma et al. 2015; Apriyanto et al., 2016).

Sandat felling technique The SFT requires two spar trees as hemp rope anchors. A hemp-based rope with a length of 40 m is used. The price of the rope was IDR10,000 m^{-1}. The lifetime of the rope was generally one year. The rope was 1.59 cm in diameter. A rope was installed 10 cm above the ground between the two spar trees (Figure 2). One end of the rope was secured to one spar tree, while the other end was loosely fastened to the other spar tree. The purpose of loosely tying the rope was to assist in lowering a fallen tree that was held by the stretch of the rope slowly down to the ground. The length of the stretched rope was varied between 5 m and 12 m.

Observation of the SFT and measurement of the time consumption of tree felling were conducted by analyzing the videos that were taken during the felling operation at the study site. The SFT was observed by identifying the phases of the technique performed in the study area and their relationship with the hemp rope as the holder of felled trees. The observed stages of the SFT were the installation of the rope (as well as its uninstallation) and tree felling. Four settings for the SFT operation were observed. The SFT was set as the location where the rope was installed to hold the

Figure 2 Installation of *sandat* technique at agroforestry private forests in the study site.

felled trees. One SFT served the 7–8 felled trees.

Private forest farmers sell their timber in the form of standing trees, so that forest harvesting activities are carried out by a team of harvesting contractors. In the SFT operation, one forest-harvesting team consisted of one chainsaw operator, one helper of the chainsaw operator, and three *sandat* operators.

A selective cutting system is used at the study site. A total of 31 trees from the forestry plant group, *sengon* (*P. falcataria*), were felled. The average diameter of felled trees was 23.4 cm and 19.95 m in total height. Other woody plants from multipurpose tree species and plantation crops were not felled.

Time study analysis The time study referred to the time spent during felling operations at the study site (workplace time, WP). The working-time classification used in this study was adopted from Bjorheden and Thompson (1995). Workplace time of the SFT was then separated into two groups: non-work time (NT) and work time (WT). WT includes productive work time (PW), supportive work time (SW), and ancillary work time (AW) (Figure 3).

The SFT consists of two operations: a *sandat* operation and a felling operation. In the *sandat* operation, the working time of installing the *sandat* includes the time spent on installation and uninstallation. The working elements of the *sandat* operation consisted of the following activities: walking to spar trees, climbing spar trees, stretching ropes, descending spar trees, lowering and retying the rope, and releasing the rope. Walking to a tree that will be harvested, preparing and clearing the understory, creating a notch and felling cut, and ultimately felling the tree were the main working elements of the tree-felling operation (Table 1).

Productivity analysis The productivity of the SFT was determined by analyzing the amount of time spent installing *sandats* and felling trees. The diameter and merchantable height of the trees for each *sandat* setting were then measured to determine *the operational production of the sandat*. Merchantable tree height refers to the length of the usable tree and was measured from a 1-foot stump height to the cutoff point at the first branch. Furthermore, the productivity of SFT operation was calculated based on the total felling time (hours) and total felling volume (m^{-3}) (Jourgholami et al., 2013).

Results

Structure and stand composition The study site comprised a variety of species and relative densities (Table 2). Twenty plant species were found in agroforestry based private forests, including two species of forestry plants, one species of plantation crops, seven species of crops, and ten species of MPTS. *Sengon* (*P. falcataria*) and *balsa* (*O. bicolor*) were planted as forest commodities. Elephant grass (RD = 46.54%), *porang* (RD = 14.23%), and cassava (RD = 10.11%) were the three most prevalent species, and were all agricultural commodities.

This study revealed three strata of the canopy at the study site: upper, medium, and lower strata. Forestry plants (*sengon* and *balsa*) and MPTS plants (durian, avocado, mango, jackfruit, and areca trees) comprise the upper stratum. The middle stratum contains species of coffee, papaya, clove,

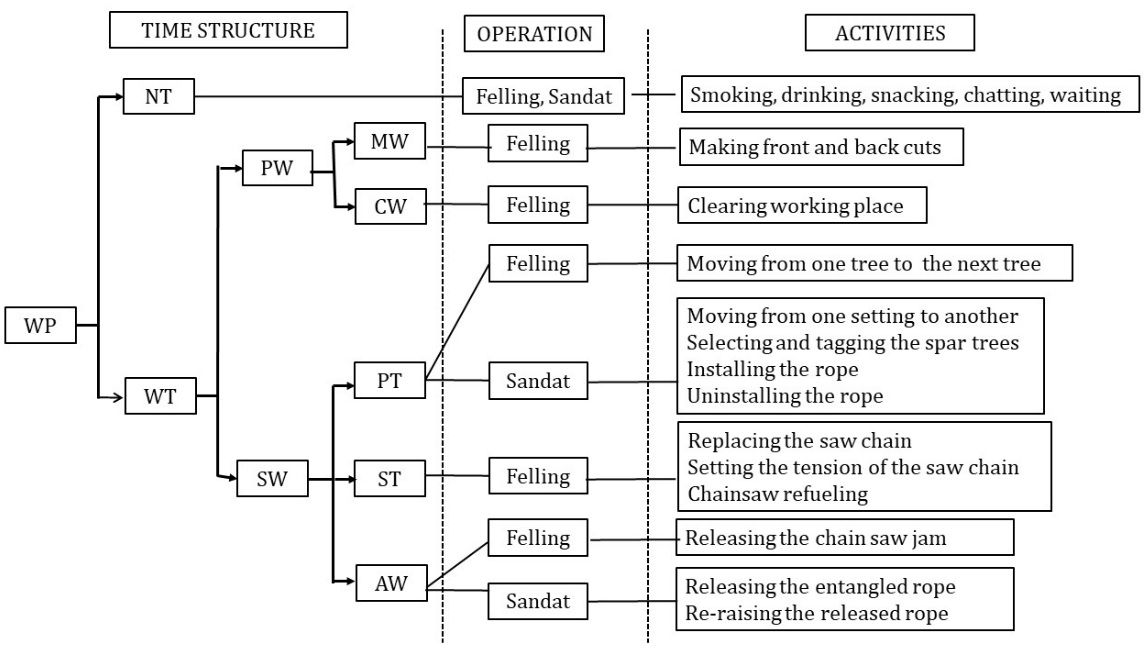

Figure 3 Time structure, operations, and activities of the SFT in Probolinggo (Note: NT = non-work time; PW = productive work time; MW = main work time; CW = complementary work time; SW = supporting work time; PT = preparation work time; ST = service work time; AW = ancillary work time; WP = work place time).

moringa, hibiscus, and banana. The lower stratum was populated with *porang*, cassava, elephant grass, chili pepper, taro, ginger, and cardamom plants (Figure 4).

Rope-assist felling procedure In the SFT operation, the selected trees to be felled are directed to the rope stretched between the two spar trees. A tree that had to fall against a stretched rope or was challenging to direct with a notch cut was manually pulled by two to three people using ropes. This depends on tree diameter. Trees with a diameter >30 cm are usually pulled by two workers, whereas those with small diameters are pulled by only one worker. The fallen tree was held with a lengthened rope and its stem was bucked in a hang-up state. Bucking began from the trunk to the top of the

Table 1 Work elements of *sandat* felling technique

Work element	Start	End
Walking to spar tree	The worker starts moving to the spar trees	The worker reaches the spar trees
Climbing spar tree	The worker starts climbing the spar tree	The worker reaches the intended height at the spart trees
Tightening and stretching rope	The worker starts tightening the rope	The rope tightened and stretched
Descending spar tree	The workers start descending toward the ground	The workers reached the ground and tightened the rope at the bottom of the spar tree
Walking to tree	The worker starts moving to the tree to be cut	The worker reached the tree to be cut
Preparing workplace	The worker starts clearing the area around the tree to be cut	The worker finished clearing the area
Making front cuts and back cuts	The worker starts making front cuts and back cut	The worker finished making front cuts and back cuts, and the tree fell down and hung up to the stretched rope
Lowering and re-tying the rope	The worker starts lowering the rope until the felled tree touched the ground	The worker finished retying the rope
Releasing the rope	The worker starts releasing the rope	The worker finished releasing the rope

Table 2 Plant density and forest stand composition of agroforestry based private forests at the study site (size of the study site: 0.59 ha; number of plot: 26 plots of 10 m × 10 m)

Species	Relative density (individual ha^{-1})	(%)	Plant classification
Elephant grass (*Pennisetum purpureum*)	2,692	46.54	Agriculture
Porang (*Amorphophallus muelleri*)	823	14.23	Agriculture
Cassava (*Manihot esculenta*)	585	10.11	Agriculture
Sengon (*Paraserianthes falcataria*)	469	8.11	Forestry
Banana (*Musa* sp.)	312	5.39	MPTS
Coffe (*Coffea* sp.)	308	5.32	Plantation
Taro (*Colocasia esculenta*)	150	2.59	Agriculture
Chili pepper (*Capsicum frutescens*)	108	1.86	Agriculture
Cardamom (*Elettaria cardamomum*)	88	1.53	Agriculture
Ginger (*Zingiber officinale*)	73	1.26	Agriculture
Balsa (*Ochroma bicolor*)	42	0.73	Forestry
Durian (*Durio zibethinus*)	27	0.47	MPTS
Areca (*Areca catechu*)	27	0.47	MPTS
Clove (*Syzygium aromaticum*)	23	0.40	MPTS
Moringga (*Moringa oleifera*)	19	0.33	MPTS
Avocado (*Persea americana*)	15	0.27	MPTS
Jack fruit (*Artocarpus heterophyllus*)	12	0.20	MPTS
Manggo (*Mangifera indica*)	4	0.07	MPTS
Hisbiscus (*Hisbiscus tiliaceus*)	4	0.07	MPTS
Papaya (*Carica papaya*)	4	0.07	MPTS
Total	5,785	100	

Note: MPTS = multi-purpose tree species

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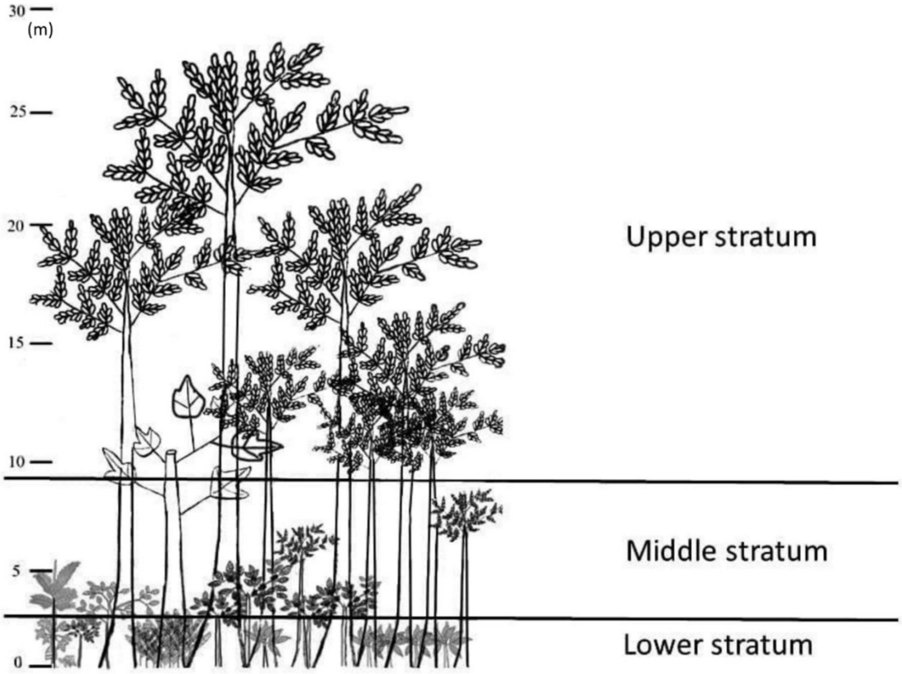

Figure 4 Vertical structure of agroforestry based private forest stands at the study site.

tree. After the initial bucking, the stretched rope gradually loosened until the fallen tree reached the ground level. After the tree reached the ground surface, bucking and debranching continued, and the rope was re-raised.

For the tree felling operation, a Chinese-made maestro plus chainsaw with a 52 cc engine capacity, 10 kg weight, and 50 cm bar length was utilized. The capacity of the chainsaw was appropriate for the diameter of the harvested trees, which were classified as small diameter trees. The chainsaw operator was 31 years old and had approximately ten years of work experience. The age of the helpers ranged from 17 to 40 years. The chainsaw operator was responsible for tree felling and bucking, whereas the helpers assisted in tree felling and bucking operations. Workers were not formally trained in felling or bucking. The harvesting operators obtained the skills and knowledge of chainsaw maintenance, felling, and bucking techniques through learning-by-doing (self-taught learning) and working experience. Forest companies, as partners of private forest cooperatives, provided training and extension in the areas of working organizations, occupational health, and safety procedures.

Working time The study showed that the WT of the SFT was greater than its NT. The average WP of the SFT was 67.04 minutes setting^{-1} (8.64 minutes tree^{-1}), which consisted of 9.43 minutes NT, and 57.61 minutes WT. Within the WT, PW was smaller than SW, with a ratio of 34.49% to 51.42%. The highest time consumption in SW was PT, which was 33.68% that of WP. The ST (11.68%) was higher than that of AW (6.10%) (Table 3). The work element with the highest work time was PT (33.68%), while AW had the lowest work time during the SFT operation (4.07%) (Figure 5).

The results of the study indicated that the SFT operation requires considerable preparation time, especially for rope installation and uninstallation. The work times required for *sandat* and felling operations were 33.34% and 66.66%, respectively. *Sandat* operation required an average of 22.42 minutes setting^{-1}, of which 13.45 minutes was for the rope installation and 9.97 minutes for rope uninstallation. The average time required to install the rope was longer than the uninstallation time. The work element with the longest working time during the *sandat* installation phase was rope lengthening (37.16%), whereas the rope-releasing element had the longest working time during the *sandat* uninstallation phase (32.04%). The tree-felling operation required an average of 44.62 minutes setting^{-1}. As much as 31.71% of the tree-felling operations were spent on making the notch cut until the tree fell.

Productivity A total of 31 trees were felled in the four SFT settings. The mean diameter of felled trees was 23.4 cm. The average total height and merchantable height were 19.9 m and 9.23 m, respectively. The tree volume ranged from 0.14 to 0.41 m^3 tree^{-1}, with an average of 0.29 m^3 tree^{-1}. The total volume of timber per *sandat* setting was between 0.99 and 3.25 m^3, with 2.30 m^3 being the average. The productivity of the SFT ranged from 0,99 to 2.66 m^3 hours^{-1}, with an average of 2.02 m^3 hours^{-1} (Table 4).

Discussion

This study demonstrated that agroforestry based private forests have a dense stand. The total density of all species was 5,785 individuals ha^{-1}. 78% of the study site's contributions came from agricultural products. Forest plants (9%), MPTS plants (8%), and plantation crops (5%) were used as the contributors. The planting pattern utilized at the study site

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Table 3 Working time structure of the SFT operations in an agroforestry based private forest in Probolinggo, East Java, Indonesia

Setting	No. of trees	Volume (m^3)	Work time (minutes)						
			NT	PW		SW			WP
				MW	CW	PT	ST	AW	
1	8	2.09	9.82	14.69	8.74	21.15	7.84	4.44	66.67
2	7	0.99	8.50	13.27	7.76	19.93	6.99	3.81	60.25
3	8	2.88	9.98	15.02	8.76	21.90	8.35	4.15	68.16
4	8	3.25	9.42	15.40	8.76	27.61	7.99	3.91	73.09
Average	7.75	2.30	9.43	14.60	8.51	22.65	7.79	4.08	67.04
Stdev	0.50	1.00	0.66	0.93	0.50	3.41	0.58	0.28	5.29
Max	8	3.25	9.98	15.40	8.76	27.61	8.35	4.44	73.09
Min	7	0.99	8.50	13.27	7.76	19.93	6.99	3.81	60.25

Note: NT = non-work time; PW = productive work time; MW = main work time; CW = complementary work time; SW = supporting work time; PT = preparation work time; ST = service work time; AW = ancillary work time; WP = work place time; Stdev = standard deviation; Max = maximum value; Min = minimum value

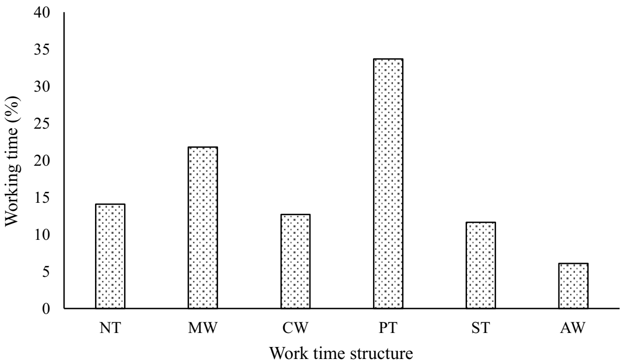

Figure 5 Time structure of the SFT in Probolinggo (Note: NT = non-work time; MW = main work time; CW = complementary work time; PT = preparation work time; ST = service work time; AW = ancillary work time).

was irregular, which made tree-felling difficult. If a tree falls directly on the ground, the risk of damage to other plants in the agroforestry system would be significant. This will inevitably result in unsustainable forest harvesting practices. Utilizing hemp rope as a tree-felling assistance in agroforestry based private forests can be considered an appropriate technique for protecting and preserving the remaining stands. According to Bianchini et al. (2021), the use of ropes in the assist-felling technique is appropriate for sustaining tree growth in harsh environments. In addition, Cedergren et al. (2002) and Nikooy et al. (2013) proposed that the issue of minimizing the damage to the remaining stands caused by tree felling can be resolved by employing an appropriate felling technique and making felling instruments readily available.

At the study site, the notch cut was imperfectly executed, a sloping top cut was not created, and there was no hinge. The only notch cuts implemented were flat-bottom cuts and felling cuts (back cuts). The felling cut reached the same height as that of the flat-bottom cut. This notching technique is commonly employed for felling small trees and private forests. Sukadaryati et al. (2008) reported that the *gmelina* (*G. arborea*) private forest in Ciamis employs the same felling technique.

Based on the time structure used in this study, there were ineffective working times during the SFT operation, namely, NT. NT is used for drinking, snacking, smoking, and waiting for work. The study obtained a higher ineffective working time than that of the previous study. Wulan et al. (2020) reported that the ineffective working time of tree felling of mangium (*Acacia mangium*) with chainsaw in industrial plantation forests ranged from 8.69 to 9.29%. The reduction in ineffective time can be accomplished by implementing a systematic work method, well planning, and organization. Campu et al. (2020) and Bianchini et al. (2021) reported that the success of rope-raising tool utilization in tree felling is determined by: a) professional training and formation, b) work organization, and c) utilization of appropriate materials and equipment.

In this study, mechanical delay (ST) and operational delay (AW) were considered as the supporting times. Mechanical delays included replacing the saw chain, re-setting the tension of the saw chain, and refueling the chainsaw. Meanwhile, releasing the chain saw jam, releasing the entangled rope, and re-raising the released rope when climbing a spar tree were considered as operational delays. Re-pulling the released rope during the rope lengthening activity occurred frequently because the tools used were frequently broken or the rope fell from the rope-raising tool. The workers did not have special tools to raise the released rope. They used wooden stems surrounding the working area. The study showed that mechanical delay accounted for the largest share of WP during SFT operation, followed by operational delay. This study obtained similar results to those of a previous study. Behjou (2009), reported that the mechanical delay causes the most inefficient work time when felling trees with a chainsaw, followed by an operational delay.

The total productivity of SFT operation in agroforestry based private forests was 2.02 m^3hour^{-1}. This result was lower than that of a previous study conducted in a gmelina private forest and mixed private forest in Ciamis, West Java, Indonesia. The felling productivities of the gmelina and mixed private forests were 4.880 m^3 $hour^{-1}$ and 3.392 m^3 $hour^{-1}$, respectively. Although the species harvested differed, the average tree diameter in the previous study

Table 4 Productivity of the SFT operations in an agroforestry based private forest in Probolinggo, East Java, Indonesia

Setting	No. of trees	Volume tree $^{-1}$ (m^3)	Total volume (m^3)	Work time (hours)	Productivity (m^3 $hours^{-1}$)
1	8	0.26	2.09	1.11	1.88
2	7	0.14	0.99	1.00	0.99
3	8	0.36	2.88	1.14	2.53
4	8	0.40	3.25	1.22	2.66
Average	7.75	0.29	2.30	1.12	2.02
Stdev	0.50	0.12	1.00	0.09	0.76
Max	8	0.40	3.25	1.22	2.66
Min	7	0.14	0.99	1.00	0.99

Note: Stdev = standard deviation; Max = maximum value; Min = minimum value

differed only marginally from that in this study. The average tree diameter in Ciamis ranged from 13.5 to 19.3 cm, whereas the range for this study was 10.19 to 37.90 cm. The felling of the private forest in Ciamis used a common felling technique applied in agroforestry based private forests, in which trees were felled directly to the ground by being pulled using a rope. During the SFT operation, the felled trees were supported with a rope in a hang-up position. The time required for the preparation and installation of the support ropes accounted for 33% of the total felling time. This is the main reason why the productivity of the SFT is lower than that of the common felling technique. In addition, the results of this analysis differed for private teak forests. Compared to the productivity of *sengon*s, gmelina, and mixed private forests, the productivity of teak (*Tectona grandis*) felling was minor. Mujetahid (2009) reported that the average harvesting productivity of the private teak forest in Bone Regency, South Sulawesi, Indonesia was 0.85 m^3 $hour^{-1}$.

SFT operations are associated with a risk of work accidents. The SFT activities that have the potential to cause work accidents are climbing trees and hanging trees falling to the ground owing to rope breaking. According to Stanek et al. (2022), tree climbing are dangerous, and numerous injuries occur during the performance of this activity. Dhafir et al. (2021) added that tree climbing is also heavy work. Data on work accidents due to tree climbing during forest operations in Indonesia are not available. As an illustration, the types and levels of tree-climbing accidents in the United Kingdom are presented. HSE (2023) reported that approximately 16% of all reported tree work accidents in the United Kingdom involve falling from a height, and about 6% are due to uncontrolled swings in the tree leading to impact with branches or the trunk. At the study site, workers climbed the trees directly. They were not equipped with personal protective equipment or assistance tools for climbing trees. The risk of work accidents in SFT operations can be reduced, among other things, by proper work planning and organization, appropriate supervision, and the use of appropriate equipment. The operation is performed by competent workers and tree climbers using a personal first-aid kit in the tree crown (Dhafir et al., 2021; HSE, 2023).

The main advantage of the SFT was that the felled tree did not directly hit the ground but was supported by a rope in a hang-up position so that the remaining plants under the felled tree were not damaged. The SFT can be considered a role model of an appropriate felling technique for harvesting agroforestry based private forests in Indonesia.

The study was conducted in agroforestry based private forests with irregular planting patterns at an average slope of 20%, and the type of wood species harvested was sengon. Meanwhile, agroforestry based private forests vary in terms of planting patterns, slopes, and timber species. The time consumption and productivity of SFT may differ depending on these three aspects. Therefore, it is useful to conduct future studies on the effects of slope, planting patterns, and timber species on the time consumption and productivity of the SFT. This study evaluated the working time and productivity of the SFT. Studies on the efficiency of operating systems, development of tools for holding fallen trees, and safety of workers are still limited. The proposed study concerning the fixation of working systems, the development of felling-supported tools, and worker safety is essential for rope-assisted felling studies.

Conclusion

The SFT is an innovation in private forest harvesting practices in Indonesia. The SFT was initially devised for agroforestry based private forests, but it is also applicable to other private forest types that employ a selective cutting system. Although this technique was initially employed for economic reasons, namely to secure coffee crops, environmental and economic concerns are now of utmost importance when employing this technique. The study found that preparation time was the largest contributor to the total working time of the SFT operation. The productivity of the SFT is lower than that of the common felling techniques used in private forests in Indonesia.

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