12th World Bamboo Congress

Taiwan, 18-22 April, 2024

www.worldbamboo.net

A work efficiency analysis by a modified bamboo harvester for clump bamboo logging

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Abstract

To promote the clumpy thorny bamboo (*Bambusa stenostachya*) harvesting efficiency and operating safety, in this study, a mature technical timber harvester, what is manufactured in Sweden, was modified on critical features to fit bamboo harvesting and to test its function and operational efficiency. Additionally, the logging efficiency with the traditional approach was compared, what the running time were measured for each treatment during harvesting procedure. The spending time of the modified timber harvester needed an average time ca. 190.3 sec culm^{-1} by one operator, it means could log average 770 culm hr^{-1}. The traditional bamboo logging approach needed an average time ca 401.9 sec culm hr^{-1} by two works, logged around 358 culm hr^{-1}. However, the harvester could be continuously operated up to 7 hrs without physical limitation, the traditional logging usually could work only for 4 hrs with physical limitation. The preliminary results showed the modified timber harvester to the culm harvesting on thorny bamboo obviously promoted the efficiency approximately up to 3.7 times on culm production, compared with the traditional logging approach. The results are helpfully to push a technical transformation of clump bamboo harvesting from the current traditional approach to a modern efficient approach for local in Taiwan.

Keywords Thorny bamboo; Clump bamboo; Timber harvester.

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1. Introduction

Taiwan is located in East Asia (21°53'50"~25°18'20"N, 120°01'00"~121°59'15"E), on the edge of the western Pacific, with an island wide area of 3.6×10^4 km^2. Taiwan has abundant bamboo resources accounting for 11.8% of the total forest area and went through a long and turbulent history of bamboo utilization. In the 1960s~1980s, bamboo-relevant industries significantly contributed to the local economy, providing jobs and revenue to bamboo farmers, local communities, and the government of Taiwan. But, due to the rise of alternative materials (such as plastic, iron, aluminum, etc.) and economy transformation, labor costs have risen. To stabilize profits and survival needs, most operators of bamboo processing factories couldn't avoid to move overseas. The bamboo industry rapidly declined after most factories shifted to China and Southeast Asia. Therefore, for decades afterwards, the economic potential of bamboo was largely neglected in Taiwan (Lin et al. 2011). However, in recent years, bamboo has enjoyed renewed attention because its rapid growth and high productivity make it an interesting option for biomass, especially due to climate change concerns and energy costs rising (Widenoja 2007, INBAR 2009, Lin et al. 2011). In addition, the higher carbon sink function is attracting most industry more attention on the effort for the net zero emission policy (Chang et al. 2018).

There are 6 main commercial bamboo species in Taiwan: Moso bamboo (*Phyllostachys pubescens*), Makino bamboo (*P. makinoi*), ma bamboo (*Dendrocalamus latiflorus*), thorny bamboo (*Bambusa stenostachya*), long-branch bamboo (*B. dolichoclada* Hayata), and green bamboo (*B. oldhamii*) (Lü 2001). The former two species are classified to monopodial style, the later four species are classified to sympodial style. Each species plays an important role in bamboo utilization, provided local farmer a variety of products for their daily needs and village economic source. Among them, thorny bamboo widely distributes over a large area in the southern Taiwan with ca 49,000 ha, some parts grow mixed with long-branch bamboo. Thorny bamboo grows in clusters, and the lower half part of the bamboo culm is surrounded by soft incisive thorny branches. As bamboo by traditional manual logging operations, to easily approach bamboo culm and smoothly saw the clump base, the thorny branches need to be removed first, which increases process difficulty and operator injury risk. However, due to the larger culm diameter (ca. 8-15 cm) and longer length (ca. 10-16 m), that means the bamboo possesses thick culm wall can be processed maximum, and the bamboo texture is tough and easy to use for furniture and construction. Before 1980s, in the southern Taiwan, Guanmiao District, Tainan City, there were various bamboo processing factories producing various bamboo products to meet the needs of food, clothing, housing and transportation in demand, such as bamboo cages, agricultural tools, bamboo furniture, bamboo pipe houses, etc., have gathered into a bamboo processing industry tribe with a huge production capacity, contributing countless rural economic vitality (Lin et al. 2011).

But like beforementioned, the rapid decline of the bamboo processing industry and the sudden reduction of bamboo consumption have affected the bamboo forest operators' motivation to do more effort to maintain the vitality of bamboo forest production though the management on felling and harvesting old bamboo. In general, thanks to thorny bamboo unique growth traits with innumerable cluttered thorny wrapped around clump base section, that make culm harvesting hard and inefficient under the current traditional manual logging approach, what evenly utilizes semi-manual treatment with chain saw to cut culm first, and then use manpower to remove thorny branches, to pull fell culm by excavator, to measure, to crosscut, to sort, … etc. Therefore, to recovery sound thorny bamboo forests, to increase bamboo supply, and to revitalize local bamboo industry, how to overcome technical obstacles on low work efficiency under current traditional logging approach is the most important first step. To develop an efficient bamboo harvesting machine while reduce labor cost, particularly for clump bamboo, always is an urgent need to bamboo forest management for local agricultural authority.

To resolve the problem for reducing production cost and promoting work efficiency, we tried to find a feasible bamboo harvester for clustery thorny bamboo logging and planning purchase and apply. But there are only some developed harvesters for running bamboo in Japan, it's rarely no harvester only for clump bamboo logging on the world market. In fact, the resemble problem happen not only in Taiwan, also in the region with abundant bamboo resource, therefore, how to mechanize the bamboo logging technology is the consensus, that should be not just for to decrease production cost, should be also promoted for its social and logistical benefits (Guerra et al. 2016). In addition, to improve worker safety (Bell 2002) and to deploy in advance the labor shortage trend in the future is a general objective to introduce mechanization as well (Spinelli et al. 2001).

In this study, an innovative combined machinery is customized modified, a mature technical timber harvester, manufactured by a machinery factory in Sweden, through some replacement of components and adjustment of operating parameters by the original manufacturer, to fit for a clump bamboo harvester, it's temporary called "modified bamboo harvester". The aim of this study is to explore the operating functions of the modified bamboo harvester, and made a preliminarily work efficiency comparison with traditional bamboo logging recorded before. The study provided a feasible way, applying an existing harvester technique, to keep developing a high efficiency harvester for clump bamboo logging uniquely.

2. Material and methods

In this study, the work efficiency of the two clump bamboo logging approaches: an existing traditional clump bamboo logging and a modified bamboo harvester, are measured. The two clump bamboo logging processes based on the character were divided into individual segment and measure its spending time in unit of "second" and to be compared mutual the entire work efficiency.

2.1. Description of study sites

The one of thorny bamboo sites for the practice of the existing traditional clump bamboo logging is located in the Longchi District, Tainan City, (22°56'23.29"N, 120°23'30.8"E), elevation on around 85 m. The other one site of thorny bamboo for the logging practice using modified bamboo harvester is located in the Liugui District, Kaohsiung City, (22°58'40.26"N, 120°38'9.3"E), elevation around on ca. 296 m.

2.2. Brief description of the two clump bamboo logging approaches

The work team of the existing traditional clump bamboo logging is consisted of 2 persons and the tools used have billhook, chain saw, excavator, steel rope, hand gloves, hand saw. Based on the operation sequence, the procedure is divided into the following steps and the spending time of each step was measured in second:

1. movement among clumps to search subject clump,
2. removement obstacle (thorny branches),
3. tying up culm by steel rope,
4. sawing bamboo culm bottom using chain saw,
5. pulling & felling bamboo culm to flat place by excavator,
6. removing lean-cross culm on the felling culm (if need),
7. removing branches and crosscutting culm based on needs,
8. stacking and sorting the segment culm based on quality and size,
9. cleaning out the residue after sorting.

Figure 1. Logging worker removing lean-cross culm on the felling culm using chain saw.

Figure 2. Logging worker removing branches and crosscutting felled culm on the flat place.

However, the abovementioned work process was not each procedure be done in each circle. Some parts of procedure were skipped based on the actual status during logging work. In total, 40 thorny bamboo culms were logged, involved in 6 bamboo clumps within 6 cycles of abovementioned logging process.

As for the bamboo harvester is one harvesting head combined with a carrier of a 12 tones excavator.

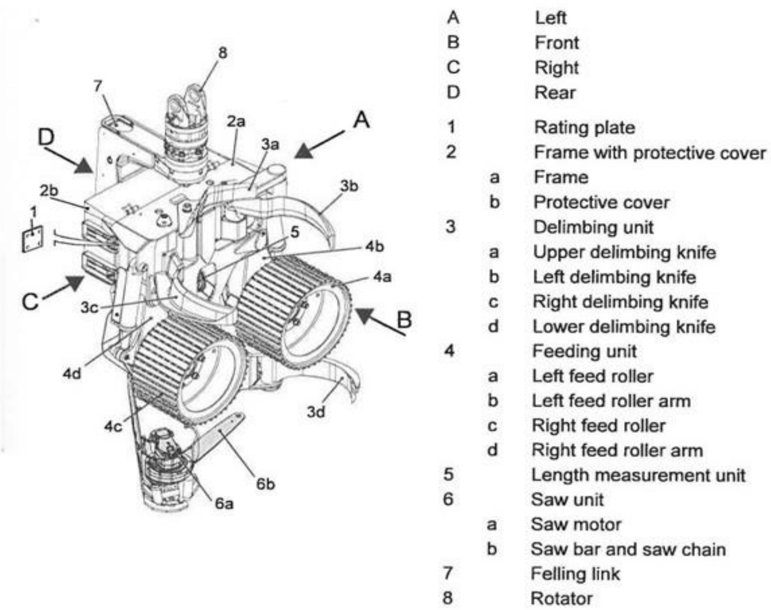

Figure 3. An overview of the harvesting head's main

The harvesting head is manufactured by a Sweden Manufacturer, Log Max, what is a professional company for timber harvester production. The main components of the harvesting head consist of delimbing, feeding with roller, length measurement, chain saw. The components of the harvesting head shown on the Figure 3. To fit bamboo logging, the two main measures were modified: the one was adopting a pair of thick rubber to replace a metal on the feeding roller surface to avoid to scratching on culm surface, and the other one was adapting the pressure of the feeding roller to avoid crushing the hollow bamboo culm. (see Fig. 4) The bamboo harvester operation just needs one operator stay in the operator's cab to complete all process from bamboo searching, closing to clump, cutting, felling & pulling, removing branches, crosscutting, stacking & sorting, and cleaning out the residue, etc. It's a continuous processing function for clump bamboo logging. There were totally 42 bamboo culms processed within 10 times of the harvesting operation.

Figure 4. A pair of thick rubber replace original metal material on the feeding roller.

Figure 5. The harvesting head possesses a continuous processing function for clump bamboo logging.

3. Results and discussion

Table 1 shown the measure results of the spending time of each procedure of the traditional clump bamboo logging approach. The operation procedures from 1-6 were mainly handling the preparation before logging on bamboo clumps, and the procedures of 7-9 were individually handling bamboo culm after logging. Among all procedures, the longest spending time was the “procedure 1” with the time of 238.5 sec for searching objective clump. The second longer one was the “procedure 2” with the time of 216.2 sec for removing the obstacle, particular the cluttered thorny wrapped around clump base section. This procedure the worker was easily injury on hand. Besides the “procedure 2”, the worker easily suffer injury without enough skill as well during the operations of the “procedure 3”, “procedure 4”, and “procedure 5”. The ‘procedure 7” with the time of 169.1 sec was the third longer time procedure, this procedure need use chain saw and more manpower to remove branches and to crosscut culm.

Table 1. The spending time of each procedure of the traditional clump bamboo logging.

Procedures	Spending time (sec)	Average (sec)
1. movement among clumps[1]	954.2	238.5±120.7
2. removement obstacle (thorny branches) [1]	864.8	216.2±122.2
3. tying up culm by steel rope[1]	692.7	115.4±90.2
4. sawing bamboo culm bottom using chain saw[1]	1003.3	167.2±112.7
5. pulling & felling bamboo culm to flat place by excavator[1]	711.5	118.6±45.9
6. removing lean-cross culm on the felling culm[1]	293.1	48.9±20.1
7. removing branches and crosscutting culm based on needs[2]	7655.4	169.1±107.1
8. stacking the segment culm based on quality and size[2]	2513.5	61.8±15.2
9. sorting out the residue after stacking[2]	1326.5	37.8±11.9

Note: [1] means the procedures steps were taken the movement among bamboo clumps.

[2] means the procedures steps were handled the individual culms after logging from clumps.

Besides the spending time directly compared, to further compare the spending time rate based on the different handling objects, the steps from the “procedures1-6” were classified to the category “pre-processing”, and the “procedures 7-9” was to the category “post-processing”. The former one mainly handles the preparation for culm logging among bamboo clumps, and the later one handles the individual bamboo culm after logging. From the Table 2. to know, the procedure “post-processing” actually needs more time to complete than the procedure “pre-processing”, the both procedures consumed time rate were 31.1% and 68.9%, respectively.

Table 2. A time rate comparison of two processing on the traditional clump bamboo logging.

Procedures	Average (sec)	Rate (%)
pre-processing	114.5±33.4	31.1
post-processing	287.4±125.5	68.9
Total	401.9±154.6	100

As for the work efficiency on the spending time of the modified bamboo harvester, because the operation by the harvesting head for clump bamboo logging is a continuous processing: firming objective culms, removing obstacle, sawing bamboo culm bottom, pulling & felling bamboo culm, removing thorny branches, crosscutting culm, stacking, sorting out, …etc. It needs more time only while the excavator takes a preparation to move, to search, and to close bamboo clump. Due to the speedy continuous processing, it's hard to measure the short time for each step during logging procedure. Therefore, we could only measure the time of the logging cycle for each bundle culm, it could be involved 1-5 culms. To easily compare with the both clump bamboo logging approaches, the operation processing also was divided into two categories: the "pre-processing" and the "post-processing". The pre-processing mainly covers the movement time for objective bamboo searching and closing, because it needs time with skill to find a feasible position to operate harvesting head in right angle and direction to take next steps smooth. As the bamboo culms were griped by the harvesting head, the forward procedures would be completed rapidly. In comparison, the modified bamboo harvester needs more over 2 times time rate (70.6%) to do the "pre-processing" than the "post-processing" with the time rate (29.4%). Table 3 shown the procedure time by the modified bamboo harvester.

Table 3. The time rate comparison of two processing on the modified bamboo harvester.

Procedures	Average (sec)	Rate (%)
pre-processing	138.5±46.7	70.6
post-processing	57.8±21.3	29.4
Total	196.3±114.3	100

The study results showed the modified bamboo harvester is feasible on the clump bamboo logging. Through the preliminarily practicing of this study, its work efficiency obviously could save time around 2 times for each culm compared with the traditional bamboo logging approach. But, the team work of the traditional bamboo logging approach could work only up to 4 hours under the physical limitation, the modified bamboo harvester no physical limitation could work up to 7 hours. In total, the work efficiency of the modified bamboo harvester on the logging culm amount could estimate to produce 5390 culm day^{-1}, and the traditional logging approach to produce only 1432 culm day^{-1}. The production capacity increased up to 3.7 times. It could produce more culms if the operator makes better operating skills through practices. In addition, the best thing is the modified bamboo harvester provides safety protection to the operator, decrease injury during the logging processing. Due to no other studies for the resemble mechanized bamboo harvesting, there is no relative results available to compare with the work efficiency of this study. In fact, there is also very few studies explored very few studies available to explore the manual bamboo harvesting, particularly for thorny bamboo harvesting among all clump bamboo species. Therefore, the preliminary results in this study provided a valuable science-based reference for managers and planners of the clump bamboo forest.

Conclusion

To revitalize local bamboo industry through supply increasement, meanwhile to consider cost reduction and workers safety during logging, to mechanize the clump bamboo logging technology is a necessary path must be actively developed. In this study, an innovated modified bamboo harvester was introduced and probed the operation for clump thorny bamboo harvesting, and few preliminary work efficiency results were obtained. The further operation efficiency analysis to explore such as work hours, yield rate, energy consumption, and operation cost, …etc., needs more measure data through more practical operations. However, no matter what the expectations on increasement of operation flexibility, promotion of work efficiency, and protection of logging worker, the modified bamboo harvester all can reach well. The study indicates the innovative bamboo harvester can handle clump bamboo logging, offering a viable alternative to manual harvesting.

Acknowledgment

The authors gratefully thank the Taiwan Forestry Research Institute, Ministry of Agriculture, Taiwan for financial support through project grants 112AS-7.4.1-FI-G2.

Conflict of interest

Authors declare no conflict of interest.

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