Research Article

Adaptation and Performance Evaluation of a Tractor Operated Wood Chipper Shredder

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Abstract | Performance evaluation of a tractor PTO operated of Chinese Wood Chipper Shredder was conducted at a farmer's field in Dera Ghazi Khan Area for processing of Eucalyptus tree top-trimmed mixed waste material with leaves. The average machine throughput capacity was found to be 503 kg.h^{-1} with an average machine efficiency of 89 percent. Total average fuel consumption and labour requirement (un-skilled + skilled) were found to be 3.5 litres and 3.53 man-hour, respectively. The machine was also tested with clean Eucalyptus stems without leaves and small branches. The average throughput capacity in this case was found to be 568 kg.h^{-1} with an average machine efficiency of 97 percent. Total average fuel consumption and labour requirement (unskilled + skilled) were found to be 2.90 litres and 3.09 man-hour, respectively.

Received | September 18, 2018; **Accepted** | January 25, 2019; **Published** | February 03, 2019
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Citation | Shahid, L.A., N. Amjad and M.A.H. Siddhu. 2019. Adaptation and performance evaluation of a tractor operated wood chipper shredder. *Pakistan Journal of Agricultural Research,* 32(1): 197-204.
DOI | http://dx.doi.org/10.17582/journal.pjar/2019/32.1.197.204
Keywords | Trimmed, Waste, Processing, Throughput capacity, Average, Requirement, Skilled and unskilled

Introduction

The Paris agreement entered into force to limit global temperature rise to well below 2°C and now affecting every country in world (Sanderson and Knutti, 2016). The United Nations adopted seventeen sustainable development goals (SDGs), which could be achieved by promoting bio-base society and circular economy (Hughes et al., 2018; Lopes, 2015). The importance and application of biomass is increasing day-by-day in developed and developing counties (Black et al., 2016; Siddhu et al., 2016). A huge quantity of lignocellulosic biomass (cellulose, hemicelluloses and lignin) produce from different sources such as forest, agricultural farms, and wood processing industries could not efficiently be utilized without-proper size given (Lindner et al., 2017; Zhang et al., 2017). Therefore, researchers should develop an effective machine, which could reduce lignocellulosic biomass size for the bare land for conserving the soil moisture, weeds control, to reduce soil erosion, to improve the soil organic matter, pellet making, and biofuels production.

The wood chipper shredder is frequently used in many sectors for increasing load density, enhanced handling and logistic capacity (Annevelink et al., 2017; Pari et al., 2017). The size of wood chipper shredder depends upon utility, field application, and economies of scale (Colantoni et al., 2017). Mobile wood chipper shredder is mostly preferred because of directly size reduction of lignocellulosic biomass

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in-situ production (Vanbeveren et al., 2017). Tractor PTO operated wood chipper shredder might be better option for most field activities (Nati et al., 2017). Moreover, large mobile wood chipper shredder is very costly and could not be depreciated without large work size, which was again difficult to attain because of seasonal use (Ladan et al., 2006). However, wood chipper shredder operation and performance are the key parameters for the selection (Laitila and Routa, 2015; Spinelli et al., 2011).

Therefore, we have undertaken the analysis in four steps. First we analyzed the present utilization of wood biomass according to different groups of users. In the next step; we analyzed the offer of wood biomass on the market and prices on the market. In the third step we made a look at the offer of modern technology for production, processing and utilization of wood biomass. In the last step we made the estimation of future development of the areas of production, processing and utilization of wood biomass.

Keeping in view the abovementioned critical steps and perception of end-users/farmers, a tractor mounted and PTO operated wood chipper shredder was identified and imported from China. The unit was assembled, special hydraulic kit installed on tractor for running the hydraulic motors of the feeding system and the unit was commissioned for first operation and pretested. Then detailed testing and performance evaluation of the unit was done at farmer's field. The purpose of the study was to evaluate at farm level for its adaptability under local conditions and create awareness among end-users through field demonstrations.

Scope of study

Field-testing and performance evaluation of wood chipper shredder unit for processing of Eucalyptus tree-top trimmed material with heavy biomass was carried out in Chotti Zareen Area, district Dera Ghazi Khan. The testing was done to assess machine processing capacity, output quality, fuel consumption, labour requirement, cost of operation and other factors affecting the machine performance.

Materials and Methods

Machine description

Wood Chipper Shredder Unit (Figure 1) is a tractor PTO operated machine consisted of three main systems namely PTO drive mechanism, chipping cum shredding assembly and feeding assembly (Spinelli and Hartsough, 2001). Raw material was fed through the chute pushed by a set of gears driven by two separate hydraulic motors. The machine was mounted type, compact, and could easily be shifted from one place to another with tractor. There are two rotary double edged cutters bolted on a rotary cast plate at 180°. One blade is stationary, which can be changed in three positions for making different chip sizes from fed material. The speed of both hydraulic motors is variable and can easily be changed. Main specifications of the machine are given as under:

Dimensions; L* W*H	**Min: 1600* 1020*1400mm**	**Working efficiency**	**8-9 $m^3.h^{-1}$**
Blade numbers	1 Stationary, 2 Rotary	Cutting diameter	Maximum 200mm
Blade turning radius	302 mm	Power required	25-50 HP
PTO RPM	540	Chips size	10-30mm adjustable

Figure 1: *Chinese Wood Chipper Shredder.*

Drive mechanism

Shredder unit is connected with tractor through three point hitch system and then PTO shaft is engaged and adjusted accordingly. Power is transmitted from tractor through PTO Shaft to main chipping/ shredding unit.

Feeder drive mechanism

A special hydraulic kit installed on the tractor was used to run two separate hydraulic motors of feeder to drive two gears in opposite direction, which push the raw material into the shredding assembly and also hold the wood stems during chipping process.

Raw material

Raw material was the main input used for processing through machine operation. Therefore, it must be ensured that the operator is well aware about the basic characteristics of raw material to be processed such as material trimming time, volume or quantity, maximum stem size and size variation, ratio of biomass to stems/solids, and purpose and use of output material. In this study the raw material processed was Eucalyptus (Lignocellulosic Biomass) tree-top trimmed waste material with leaves and branches (Assirelli et al., 2013) as shown in Figure 2.

Figure 2: *Raw Material to be processed.*

Machine operation parameters

The number of replications, time elements (chipping and shredding time, machine clogging, adjustment, and repairing time etc.), throughput capacity, chip size and its quality, fuel consumption, and total labor requirement (unskilled and skilled).

Number of test replications

There is not any thumb rule about the number of replications. Generally, it depends upon the situation and availability of total raw material for processing during the unit testing. A minimum average of three replications needs to be taken for reliable data sets.

Sample size and weight

The raw material was gathered in three different sample piles. Each sample pile was weighed with the help of spring balance as shown in Figure 3. The weight of each sample was denoted as samples 1, 2 and 3 in kg (tons), respectively.

Figure 3: *Sample weighing for unit testing.*

Fuel consumption

Tractor fuel tank was filled with diesel fuel up-to the neck level at the start of the first test operation. Sample one was processed through normal running of machine. Total time of operation for processing sample one completely was noted with the help of a stopwatch in minutes. Then tractor was stopped after completing the processing of sample one and the fuel tank was refilled with diesel. Total refilled diesel with the help of a beaker was the total fuel consumed for processing of sample one as shown in Figure 4. Same procedure was repeated in the same way for the processing of samples two and three, respectively. Total fuel consumption in liters per unit time was calculated (Nati et al., 2010).

Figure 4: *Measurement of fuel consumption*

Time elements

Two different stopwatches were used to measure the various time elements such as total time taken by each specific operation for the processing of specified raw material samples. The total time lost during different operations was also measured. It included the time for delays, machine chocking, breakdowns and spent on minor repairs/adjustments.

Throughput capacity

It was calculated in processing of tree-top trimmed material (stems with leaves and branches) in kg/h by using the formula (Weerasooriya et al., 2017).

$$\text{Throughput Capacity: C} = \frac{W}{T}$$

Where;

W is weight of material to be chipped/shredded in kg and T is total processing time in hours (h).

Labour requirement

The standard procedure was adopted for determining the total labour requirement for mechanical wood chipping shredding of tree-top trimmed waste material. Total man-hours required for each machine operation in specified time segment were recorded during machine testing at farmer's field. Then total labour requirement per ton of tree-top trimmed waste was worked out (Weerasooriya et al., 2016). Figure 5 elaborated the complete wood chipping and shredding process.

Uses of output material

One of the use was to sell the processed/output material to brick factories as fire-fuel or use as organic matter for mulching in the unfertile soils. Pure chips could be used for covering pathways and farm roads and pods of ornamental plants etc.

Cost of operation

It consisted of fixed and variable costs. Fixed costs are related to the ownership and occurred regardless of the machine use. Hourly fixed costs are inversely proportional to the amount of annual use. Variable cost is directly related to the machine use. It included the repairs and maintenance (RandM) cost, POL cost and servicing (Acuna et al., 2012; Ghaffariyan et al., 2017).

Figure 5: *Raw material, wood chipping and shredding process and output material.*

Results and Discussion

The machine performance results such as machine throughput capacity, efficiency, fuel consumption, labour requirement, and comparison of results for processing different raw material and cost of operation were discussed in this section.

Data collection

The general information and other related data recorded before the testing and performance evaluation of wood chipper shredder such as site location, tree type and species, hiring rates of daily paid casual labour and presented in the Table 1.

Table 1: *Basic informative and field data recorded before unit testing.*

Sr. No.	Items	Description
1	Name of Farm	Laghari Agriculture Farm,
2	Location	Chotti Zareen Road, district Dera Ghazi Khan
3	Raw material	Eucalyptus Tree-top trimmed material along-with leaves
4	Material condition	More than two weeks old after trimming
5	Machine name	Chinese tractor PTO operated wood chipper shredder
6	Type of labour	Causal hired labour on daily basis: unskilled @Rs. 450 per day and skilled Rs 800/day
7	Uses of output material	Sale price of output material as firewood to brick factory owner @ Rs 120/Mond (40 kg)

Processing of tree-top trimmed waste material

The wood chipper shredder was evaluated for the processing of tree-top trimmed waste material of Eucalyptus boarder trees. Results presented in Table 2 revealed that machine processing capacity varied from 493 to 511 kg.h^{-1} with an average throughput capacity of 503 kg.h^{-1}. The machine efficiency varied from 81 to 96 percent with an average of 89 percent. Total fuel consumption varied from 3.3 to 3.6 L.h^{-1} with an average of 3.5 L.h^{-1}. Total average labour requirement (un-skilled and skilled) was found to be 2.35 and 1.18 man-hrs, respectively.

Processing of tree stems without leaves and branches

Wood chipper shredder was also tested with clean stems without leaves and branches at farm level. Results presented in the Table 3 showed that the throughput capacity of wood chipper shredder varied from 545 to 582 kg.h^{-1} with an average of 568 kg.h^{-1}. Machine efficiency varied from 92 to 100 percent with an average of 97 percent. Total fuel consumption varied from 2.7 to 3 L.h^{-1} hour with an average of 2.90 L.h^{-1}. Total average labour requirement; unskilled and skilled was found to be 2.06 and 1.03 man-hrs, respectively.

Table 2: *Machine performance data for processing of tree-top trimmed waste material.*

Sr. No.	Parameters	T_1	T_2	T_3	Mean
1	Sample weight (kg)	210	230	230	223
2	Processing time (min)	25	28	27	27
3	Machine chocking and adjust. time(min)	6	3	1	3
4	Fuel consumption(litres)	1.45	1.70	1.50	1.55
5	Total time (min)	31	31	28	30
6	Fuel consumption (L/h)	3.5	3.6	3.3	3.5
7	Processing capacity (kg/h)	504	493	511	503
8	Machine efficiency (%)	81	90	96	89
9	**Labour Requirement (man-hrs.)**				
	i) Unskilled	2.40	2.17	2.48	2.35
	ii) Skilled	1.20	1.09	1.24	1.18
	Total (i + ii)	3.60	3.26	3.72	3.53

Table 3: *Machine performance data for processing of stems without leaves and branches.*

Sr. No.	Parameters	T_1	T_2	T_3	Mean
1	Sample weight (kg)	96	100	97	97.67
2	Processing time (min)	10	11	10	10.33
3	Machine chocking and adjust. time(min)	0	1	0	0.33
4	Total time (min)	10	12	10	10.67
5	Fuel consumption (litres)	0.50	0.60	0.45	0.52
6	Processing capacity (kg/h)	576	545	582	567.82
7	Machine efficiency (%)	100	91.67	100	97.22
8	Fuel consumption (L/h)	3.00	3.00	2.70	2.90
9	**Labour Requirement (man-hrs.)**				
	i) Unskilled	2.00	2.18	2.00	2.06
	ii) Skilled	1.00	1.09	1.00	1.03
	Total (i + ii)	3.00	3.27	3.00	3.09

Comparison of machine performance parameters

Comparison of fuel consumption: Figure 6 showed that fuel consumption was comparatively more in case of clean wood stems as compared to tree-top processing trimmed material with leaves, which probably happened due to two things; less waste of operational time in machine chocking and/or in minor machine repairs and breakdowns and also easy feeding of clean wood stems.

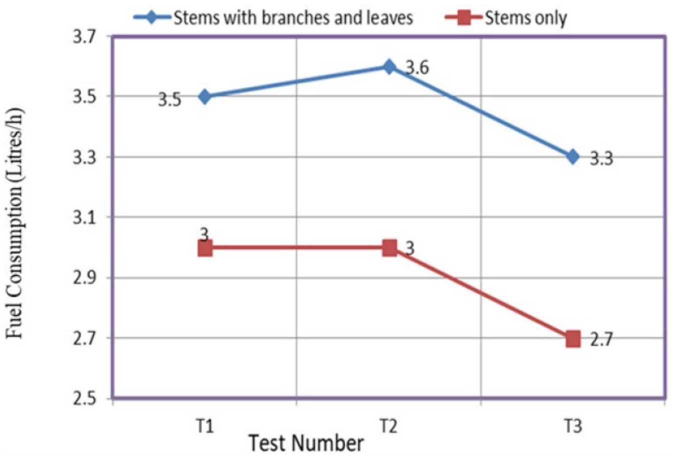

Figure 6: *Comparison of fuel consumptions for processing two different raw materials.*

Comparison of throughput capacities: Figure 7 depicted that material processing capacity was comparatively more in case of processing tree stems only as compared to bulky material with branches and leaves, which mainly occurred due to easy material feeding of clean stems and also less breakdown and/or machine chocking during field operations.

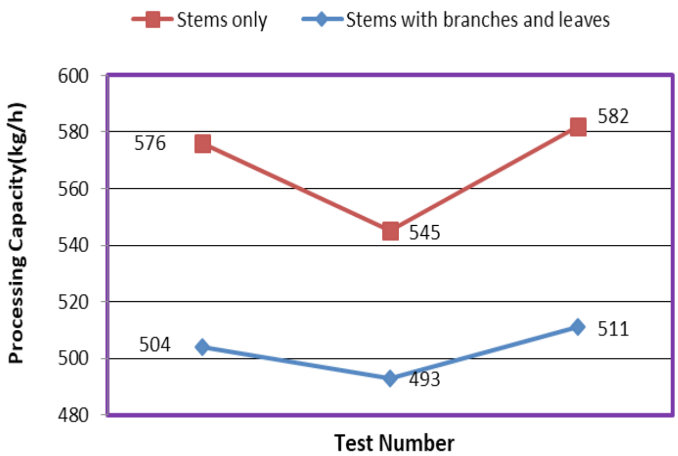

Figure 7: *Comparison of throughput capacities for processing of two different raw materials.*

Comparison of machine efficiencies: Figure 8 showed the fact that machine efficiency was comparatively more in case of processing tree stems only as compared to bulky tree-trimmed material with branches and leaves, which mainly occurred due to easy material feeding of clean stems into the machine and also less wastage of operational time in minor machine breakdowns and/or chocking during field operations.

Total operational cost: Total operational cost of wood chipper shredder consisted of fixed costs and variable costs. The estimated fixed and variable costs were found to be 75 and 504 rupees per hour of machine operation, respectively. Total operational cost of machine was found to be rupees 579 per hour and rupees 1151 per tonne of tree-top trimmed waste material processed by the machine (Table 4).

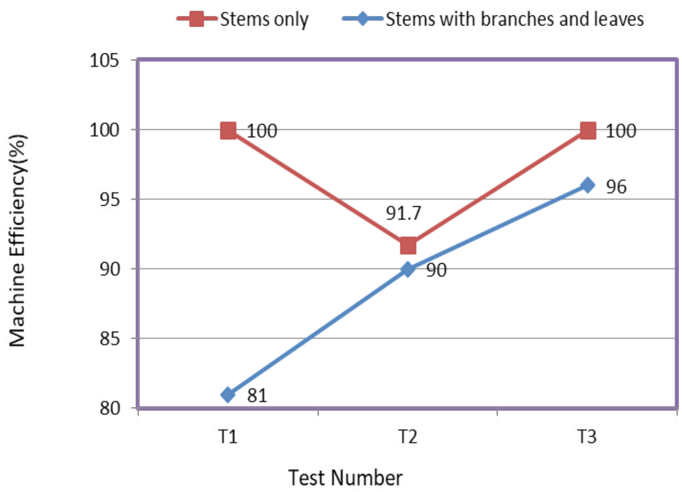

Figure 8: *Comparison of machine efficiencies for processing of two different raw materials.*

Table 4: *Total and operational cost for mechanical wood chipping shredding.*

Sr. No	Parameters	Units	Quantity
1	Machine capacity	kg/h	503
2	Fuel consumption (Diesel)	L/h	2.97
3	Labour requirement i. Unskilled (material processing) ii Skilled (Operator)	man-hrs	3.53 2.35 1.18
	Fixed cost	Rs/h	75
	Variable cost	Rs/h	504
	Total Operational Cost	Rs/h	579
	Total Operational Cost	Rs/ton	1151

Conclusions and Recommendations

The following conclusions were drawn on the basis of field experience and machine performance study:

1. The machine performed well at farmer's field. Its processing capacity ranged between 493 to 511 $kg.h^{-1}$ for the whole trimmed material with leaves and branches and from 545 to 582 $kg.h^{-1}$ for pure stems, respectively. Machine efficiency ranged from 81 to 97 percent and 92 to 100 percent, respectively depending upon the condition of

trimmed material with or without leaves and branches.

- The tree type, species, time of harvesting, and condition (material; bushy or straight) is very important and crucial; learned during machine testing that material lying in the field for more than two to three weeks is comparatively more difficult to process due to fibrous dominance.
- The processing of non-bushy stems and material was much easier than bushy and bulky material.
- The fine chipped material frequently chocked the machine operation as compared to long chipped material.
- The processing of tree trimmed waste material within a week of its harvesting was comparatively easy as compared to old material. It required less PTO power during processing.
- The processing of less fibrous material was easy for the machine and tractor.

2. The sharpness of rotary blades is rapidly reduced during processing of old harvested material as compared to fresh harvested material.
3. The chip size and quality of chipped output material also depends upon the presence of outer and inner fibrous material.

Field experience and technical problems faced during unit pretesting, field testing and performance evaluation of wood chipper shredder have suggested that following modifications/adjustments should be incorporated into the prototype before its commercialization:

1. The housing of chipper shredder assembly should be redesigned and installed in such a way that frequent machine chocking must be minimized and/or removal of any chocked material inside the housing should be easy to remove during operation.
2. The machine chipper cum shredder assembly should be redesigned in such a way that it could perform both operations: chipping and shredding separately. Then the same machine could be used as chipper shredder for clean and bigger stems and chopper shredder for tree-top trimmed waste material with heavy leaves and branches.
3. Additional small conveyor should be designed and installed before the feed gear set for easing the material feed and control vibration of heavy fed material.
4. Hydraulic motors of feeding control system may be replaced with mechanical system, which could easily be used with easily available different models of tractors at farm level.

Acknowledgements

The authors extended their sincere thanks to the management of Agricultural Engineering Institute (AEI) for logistic as well as technical support during the field testing and performance evaluation of Chinese Wood Chipper Shredder at farmer's field in Dera Ghazi Khan Area. Paid special thanks to the technical team members consisting of one engineer and two technicians.

Furthermore, the authors had to pay sincere gratitude and thanks for the hospitality, on-farm cooperation and support such as availability of abundant tree-top trimmed material, tractor with tractor operator and trolley during field testing and performance evaluation of Chinese's chipper shredder unit.

Authors' Contribution

Liaqat Ali Shahid: A research and development project titled "Adaptation and Commercialization of a Tractor PTO Operated Wood Chipper Shredder" was run for a period of three years by the first author as a project Incharge.
Nadeem Amjad: Main facilitator throughout the research and development process and also contributed in the writing, final proof reading and editing the contents of this research paper.
Muhammad Abdul Hanan Siddhu: Assisted in conducting field testing, performance evaluation and demonstration of identified wood chipper shredder machine at farmer's field and also assisted in preparation of test report and final draft of this research paper.

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