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Utilization of woody pruning residues of apple trees

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ABSTRACT
Utilize agricultural residues from pruning brings many advantages including employment, social and economic benefit, rural development, natural forest protection, increased energy efficiency, and lower costs of raw material for the production of particleboard industry. In this study, the use of wood utilization of pruning residues from apple trees has been investigated by using chipping at the landing chipping methods (LCMs) and farm chipping methods (FCM). These methods were conducted on seven farms, totaling 9.2 ha. A time study was used to estimate operation time and cost. Transportation of chips from the study area to factories was done with semi-trailers, trucks, and pickup trucks. The residue yield was between 1.8 and 2.0 green ton per hectare. The maximum time was related to chipping and the collection of residues and the most delay was mechanical. The residues were collected, chipped, and transported to the particleboard factory at a cost between US$10.18 and US$19.46 per ton, and the profit rate between US$15.5 and US$24.8 per ton depending on chipping methods and secondary transport system. Cost and the total time of LCM were lower than the FCM, and also production rate of LCM was higher than the FCM; therefore, this method was more effective in processing residues from apple trees. Regression techniques showed that in LCM, the effect of diameter and age was significant on residue processing time and in FCM, the effect of diameter, age, residue density, and functional the area was significant in residue processing time.

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Chipping method; machine hour rate; production rates; pruning residues; wood waste biomass

1. Introduction

Rural development is the process of improving the quality of life and economic well-being of people living in rural areas, often relatively isolated and sparsely populated areas (Moseley 2003). Rural development has been traditionally centered on the exploitation of land-intensive natural resources such as agriculture and forestry. Education, entrepreneurship, physical infrastructure, and social infrastructure all play an important role in developing rural regions. Emphasis on locally produced economic development and job creation strategies characterized rural development (Ward and Brown 2009).

Agricultural residues include all the organic materials which are produced as by-products from agriculture activities and gardening (Dyjakon 2019). Globally, 140 billion metric tons of biomass is generated every year from agriculture (UNEP 2009). For the future, however, the share of agricultural residues is predicted to grow significantly and these residues constitute a major part of the total annual production of biomass (Baruya 2015). This volume of biomass can be converted into an enormous amount of energy and raw materials for the particleboard industry. As raw materials, biomass residues streams have attractive potential for large-scale wood-based industries and community-level enterprises. These residues are of high value as a raw material for further use, according to the precepts of the circular economy. Improper management of residual agricultural biomass is contributing toward climate change, water, and soil contamination, and local air pollution. Public and private agencies made considerable efforts to manage agricultural residues and to convert them into useful products. However, there are still major gaps to fill, and among them the lack of awareness and capacity to cost-effectively convert residues into raw material (UNEP 2009).

Woody residues are the most promising source of raw materials for the wood industry (Yoshioka et al. 2006), especially in countries with low forest cover (LFC). For example, commercial forests cover two million hectares (about 1.2% of the country area) in the north of Iran, however, the Iranian Parliament passed a law banning all logging in the commercial forests for 10 years, so utilization of the forest has recently been banned completely (Financial Tribune 2017). One of the woody residues involves cut branches from permanent tree crop pruning, such as vineyards, olives, apples, etc. (Castillo-Ruiz et al. 2017; Toscano et al. 2018).

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Apples are one of the most common fruit crops in temperate regions. On a global scale, they cover 4.9 million hectares (FAOSTAT 2009). These trees require annual pruning and thus generate a substantial amount of residues, which must be disposed of. Finding some use for orchard pruning residues would allow converting a disposal problem into a collateral production, with a potential for revenues or reduced management costs (Spinelli and Picchi 2010). In fact, pruning residues could replace traditional wood assortments for bioenergy and industrial use (Ntalos and Grigoriou 2002; Bernetti et al. 2004). Pruning residues management practices are designed to dispose the waste wood that is produced after tree pruning (La Cal Herrera 2013). However, these practices have mostly been studied following only econometric approaches (Parra-López and Calatrava-Requena 2005; Rodríguez-Entrena et al. 2014). In many parts of the world, the main shift is designed to dispose of residual wood by burning to recovery through chipping (Benyei et al. 2017). In Iran, there are more than 217,000 hectares of apple orchards and their annual pruning produces more than 400,000 tons of wood residues (Ministry of Agriculture 2018). Apples trees covered a wide area from west to northeast in Iran and pruning residues of apple trees are burned (with the exception of wood with a diameter larger than 15 cm). The study on the effect of Apple pruning wood particles mixed with industrial wood particles for particleboard manufacturing was showed that mechanical properties of panels such as MOR, MOE, IB, TS, and WA while they were improved as the Apple pruning wood particles increased (Enayati and Yousefi Hosseini 2008; Kowaluk et al. 2020). Their results showed that adding an increasing amount of nanoparticles and using a higher weight percentage of apple pruning particles improved flexural modulus, flexural strength, and internal bonding strength of the boards.

Although, Improvement of physical and mechanical properties of particleboard made of apple tree pruning was reported; So far no plans have been put forward for the optimal use of these resources, which may create additional raw material for the industry and at the same time solve a problem common to most farmers, gardeners, and municipalities (Azizi 2006). On the other hand, in these areas, a wide range of agricultural land is under fast-growing tree species, especially different poplar clones, which can be used as a complement to apple branches in the production of particleboard. Studies have shown that particleboards made of mixed apple tree branches and poplar wood (ratio 50:50) have a higher bending strength and elasticity modulus than particleboards made from apple tree branches only (Kargarfard et al. 2006).

In order to utilize pruning residues as a lignocellulosic source for particleboard production, it is a critical issue to have a good plan. In turn, planning requires a correct estimate of chipping productivity and cost. Underestimating chipping costs will eventually result in a financial loss for the operator/contractor, whereas an overestimate will make the operator/contractor much less competitive. This is particularly important for operations that are characterized by borderline profitability (Heikkilä et al. 2007; Hartsough et al. 2008), where a correct estimate of harvesting productivity and cost is necessary for deciding whether to salvage some biomass products or treat to waste. Similar problems are faced by prospective operators, who are equipping to get into the chipping business and need as much detail as possible on the productive and economic performance of alternative choices under their work conditions. Finally, a correct estimate of productivity is crucial to the success of any production-based pay system (Toupin et al. 2007).

In the world, many researchers have estimated the efficiency of manual or mechanized harvesting systems (Vanbeveren et al. 2015) and technology alternatives as a single-phase pruning and harvesting machine (Spinelli et al. 2011). Also, they have investigated commercial and two-phase harvesting (Magagnotti et al. 2013) and other technologies for tapping and transporting the pruning residue resource (Laitila 2016). Machine manufacturing factories have designed many systems to retrieve pruning residues, which are equipped with a variety of tools. In Iran, chippers are also designed for use in small-scale urban green spaces, which can be set at a landing or carried by a farm tractor into the stand. Given that this technology is native and based on native knowledge; its spread will be accompanied by job employment and economic development in rural areas. The technical retrieval of pruning residues is associated with business prosperity, leading to the flow of money and the improvement of the economic situation of the rural. The goal is to estimate chipping productivity and cost when applying a small-scale locally-manufactured chipper to the comminution of pruning residues.

2. Materials and methods

2.1. Experimental site and species

The current research was conducted in Damavand city (Jaban village), Tehran province (35°37′58″N, 52°15′50″E) in Iran (Figure 1). Damavand city is located 45 km east of Tehran and the city area is 1759.47 km^2. The altitude is 2050 meters and precipitation is not the same due to the mountainousness of the area; in general, the average annual rainfall is 385 mm per year. The coldest month and hottest month of the year are January and July, respectively. In the Damavand, tree species of apple, pomegranate, walnut, cherry, and peach are grown. The area of apple orchards in this city is 7500 ha (Ministry of Agriculture 2018). This study was tested on seven sites, totaling 9.2 ha. In these sites, the distance between apple trees was 3–4 m and the number of trees was approximately 600–1100 per hectare. The trees were between 8 and 20 years old and 8–45 cm in diameter.

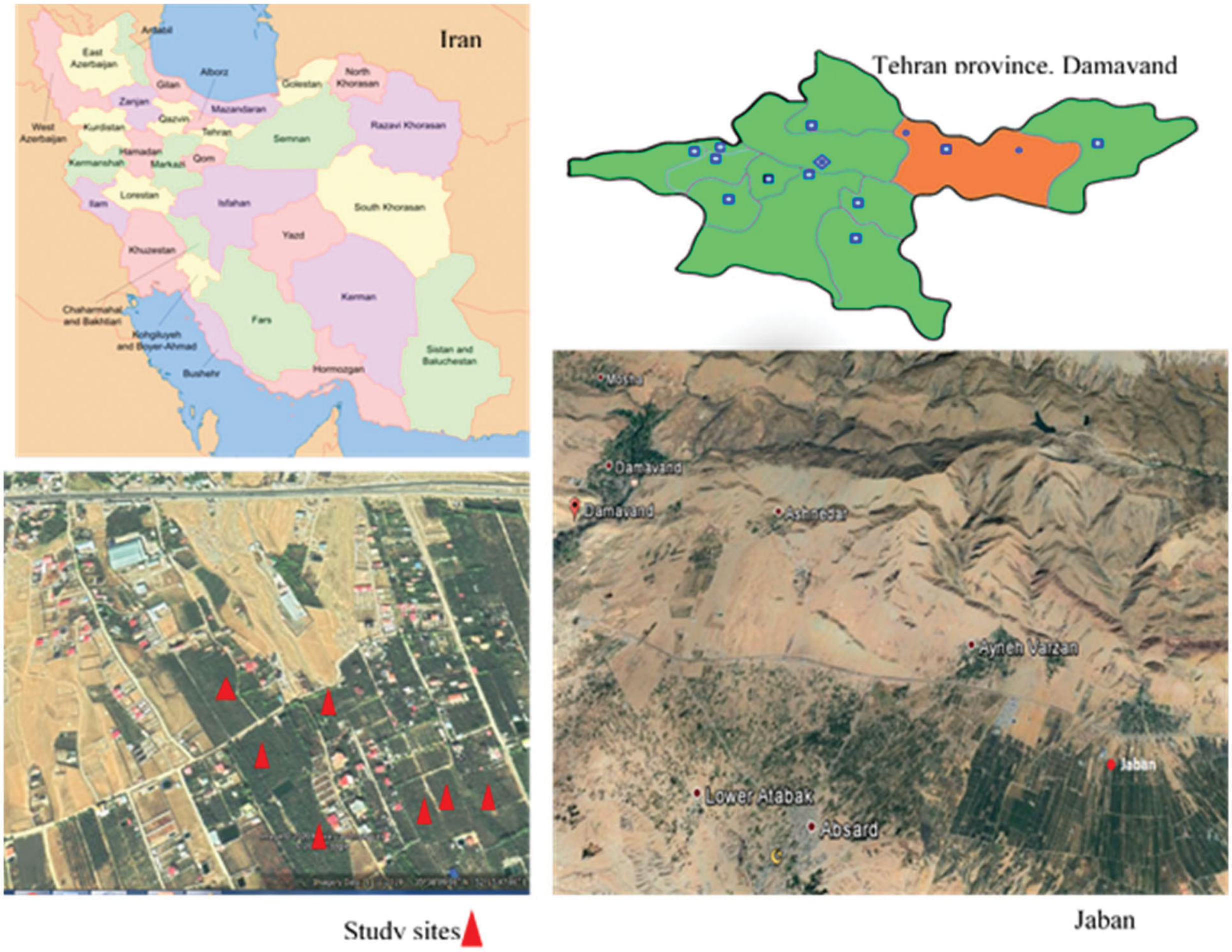

Figure 1. Study sites in Damavand city located in Tehran province.

Figure 2. Woody pruning residues of apple trees and processing with chipper KOREN K 17000.

2.2. System description

In this study, a small chipper, KOREN K 17000 (Figure 2) was used for processing apple pruning residues in associated with two harvesting methods: (i) Landing Chipping Method (LCM) and (ii) Farm Chipping Method (FCM). In LCM, the chipper was deployed in the empty space in the gardens

Table 1. Technical description of KOREN K 17000.

Model	Engine	Engine power	System dimensions	Chip capability	Chips Dimensions
KOREN K 17000	Honda petrol	13 horsepower	2*1*1.5 m	Up to 10 cm	1*1*3 cm

(generally the field's edge) and residues were collected manually and stacked in this space and processing with the chipper. Technical description of KOREN K 17000 is presented in Table 1. In this method, the workforce was needed to collect residues and operate the machine. But in FCM, the chipper was attached to a standard agricultural tractor and traveled between the trees in specified paths of the orchards and chipped the residues. In this method, in addition to the workforce to collect residues and operating the machine, the tractor driver was also needed. Transportation of chips from the production sites (orchards) to factories was done with semi-trailers, trucks, and pickup trucks, with a payload of 24, 16, and 3 tons, respectively.

2.3. Machine hour rate estimation

Machine hour rate is the cost of running a machine per hour. It is a useful method to estimate machine expense of production. The operation broke down to elements and then the machine was treated in the tested area (60 cycles for each harvesting method), so that all overhead related to the machine was identified.

The continuous time study was used to collect the required data at the cycle level. The LCM included the following work steps: collect the residues manually, loading the residues into the chipper and chipping, packing, loading the chips into the secondary transport machine, transport to the factory, and delays (organizational, mechanical, and personal delay). Also, the FCM included the following steps: empty travel, establishment (setting up the machine), collect the residues and unloading into the chipper, chipping, packing, loading, transport to the factory, and delays (organizational, mechanical, and personal delay). Cumulative timing was used to determine the standard time of operation. In the cumulative timing, the time continues from the beginning of the first element to the end of the last element and the time of each element is recorded. Time was recorded using a stopwatch, while output was determined by measuring the weight of the chip produced during operation.

Machine hour rate was obtained by dividing the total running expense of the machine during the time study by the number of hours in which the machine was operated (Miyata 1980). The information required was divided into two parts i.e., fixed and variable expense. The purchase price, economic life in hour, repair and maintenance, and annual use in an hour were obtained from the factory which made the machine. Operation cost (USD h^{-1}) was estimated by summing up a machine running expense per hour, crew wage (operator and labor involved with the collection, chipping, packing, and loading) and tractor hire (in FCM). Production cost (USD t^{-1}) was calculated by dividing machine hour rate by the weight of produced chips (ton). Total cost (USD t^{-1}) included production cost and transportation costs (with pickup truck, truck, and trailer) (Ghaffariyan et al. 2013; George et al. 2019).

2.4. Data analysis and modeling

Data were statistically analyzed with regression techniques to calculate any significant relationships between chipping time and significant independent variables using SPSS var.18 software. In the current research, the independent variables were the distance between orchards, orchard area, residue density in field, the distance between trees and diameter and age of trees. The variables were selected according to previous studies and the feasibility to measure them regarding the budget and time limitations. Paired *t*-test was used to detect significant differences between the two work methods: FCM and LCM. Each of the study sites was split in two and the two methods were applied on each half. So *t*-test was used to compare the time and production of the two methods. Normality of data was assessed by Kolmogorov–Smirnov test.

3. Results

3.1. Work and time study

A total of 60 cycles were studied for each harvesting method in tested sites. The results of the cumulative timing showed that in LCM, the largest proportion of worksite time was related to chipping and the collection of residues in the field was the second time-consuming element too (Table 2). With the method, the majority of delay time was due to mechanical causes (53.69%). Similar results were obtained for FCM, where chipping (37.21%) and residue collection (16.44%) took most of the worksite time, although their incidence over the total was lower than for the LCM. Again, mechanical causes (47.33%) accounted for the majority of delay time, together with organizational issues (38.67%). Cycle time without delays was 186.40 and 247.50 min per ton of produced chips in LCM and FCM, respectively. Also, delay time in LCM (20.30 min t^{-1}) was less than FCM (30.00 min t^{-1}) (Table 2).

3.2. Production and cost

Residue yield was included between 1.8 and 2.0 green tons per hectare. Table 3 shows the machine hour rate including fixed, variable, and crew wage, for both

Table 2. Distribution of cycle time and delays in two work methods (Per ton of produced chips).

	LCM		FCM	
Elements of each cycle	(min.)	(%)	(min.)	(%)
Empty travel	—	—	25.00	10.10
Establishment	—	—	11.20	4.53
Collect the residues	56.00	30.04	40.70	16.44
Chipping	74.40	39.91	92.10	37.21
Packing	21.40	11.48	34.80	14.06
loading	5.70	3.06	11.50	4.65
Transport to the factory	18.00	9.66	18.00	7.27
Mechanical delay	10.90	5.85	14.20	5.74
Cycle time without delays	186.40	100.00	247.50	100.00
Delays				
Mechanical delay	10.90	53.69	14.20	47.33
Personal delay	4.40	21.67	4.20	14.00
Organizational delay	5.00	24.63	11.60	38.67
Delays time	20.30	100.00	30.00	100.00

Table 3. Production and cost of utilizing woody pruning residues of apple trees.

Production and cost	Unit	LCM	FCM
Residue yield	t ha^{-1}	1.80–2.00	1.80–2.00
Production rate (with delay)	t h^{-1}	0.15	0.12
Production rate (without delay)	t h^{-1}	0.16	0.13
Purchase price	US$	700.00	700.00
Economic life	Year	10.00	10.00
Annual use	SMH $year^{-1}$	1600.00	1600.00
Fixed cost			
Depreciation	US$	73.85	73.85
Interest on capital	%	12.49	12.49
Insurance	US$	8.63	8.63
Total fixed cost	US$ PMH^{-1}	0.06	0.06
Total fixed cost	US$ SMH^{-1}	0.05	0.05
Variable cost			
Fuel, Oils and lubrication	US$ h^{-1}	0.08	0.08
Repair and maintenance	US$ h^{-1}	0.04	0.04
Tires and blade	US$ h^{-1}	0.02	0.02
Total variable Cost	US$ h^{-1}	0.14	0.14
Machine rate	US$ h^{-1}	0.21	0.21
Labor cost	US$ h^{-1}	1.07	1.00
Tractor hire	US$ h^{-1}	—	0.57
Operation cost	US$ h^{-1}	1.28	1.78
Production Cost (with delay)	US$ t^{-1}	8.40	14.32
Production Cost (without delay)	US$ t^{-1}	8.00	13.46
Total cost			
Transport with pickup truck	US$ t^{-1}	14.00	19.46
Transport with truck	US$ t^{-1}	10.18	15.65
Transport with trailer	US$ t^{-1}	10.50	15.96
Income	US$ t^{-1}	35.00	35.00
Profit rate			
Transport with pickup truck	US$ t^{-1}	21.00	15.53
Transport with truck	US$ t^{-1}	24.81	19.34
Transport with trailer	US$ t^{-1}	24.50	19.03

h: hour; PMH: profit machine hours; SMH: scheduled machine hours; t: tone.

harvesting methods. The highest component of the total cost was crew wage (US$1 and 1.07 per hour in LCM and FCM, respectively). With FCM, a tractor was used to carry bags to landing and the cost of this machine (US$0.57 per hour) was added to the total cost. Operation cost was US$1.28 and 1.78 per hour, and the production cost was US$8.40 and 14.32 per ton in LCM and FCM, respectively. The total cost of collecting, chipping, and transporting the residues was between US$10.18 and US$19.46 per ton, whereas, profit rate between US$15.5 and US$24.8 per ton depending on chipping methods and transport machine. The FCM was more expensive than LCM. In contrast, the productivity rate of LCM was more than FCM, which resulted in a lower machine hour rate in LCM compared to FCM. The lowest cost and the highest benefit rate were obtained LCM and transport with the truck.

3.3. Regression models for productivity rate of chipper

In order to predict the processing time, distance between orchards (m), orchard area (ha), residues density (m^3/ha), distance between the trees (m), diameter (cm), and age of trees (year) were entered in multiple linear regression (Table 4). In FCM, in addition to the above variables, functional area (m^2), (the area of the orchard that its residues are chips in per cycle) was entered in regression (Table 5). In LCM, the regression model showed that the effect of the diameter and age of trees are significant at $\alpha < 0.01$ and so these variables have entered the regression equation. Also, the standardized coefficients (beta) showed that the effect of tree diameter is stronger than the age of the trees (the higher the beta weight indicates the effectiveness of the independent variable's role on the dependent variable). The coefficient of determination (R^2) showed that 77% of the dependent variable (processing time) changes are explained by independent variables (diameter and age of trees) and the rest of the dependent variable changes are related to other factors. In FCM, the results showed that the effect of diameter and age of trees and residues density on the processing time are significant at $\alpha < 0.01$ and the effect of functional area is significant at $\alpha < 0.05$. Also, the beta weight showed that the effect of the age of trees on the processing time is the strongest. In this method, the coefficient of determination (R^2) showed that 64% of the dependent variable changes were explained by independent variables (Table 6).

3.4. Comparison between work methods

Kolmogorov–Smirnov test results showed that the significance level is higher than 0.05, so the data have normal distribution. Paired t-test results showed that the difference between the production and time without delay in LCM and FCM are significant at $\alpha < 0.01$. Difference between the total worksite time (including delays) and organizational delays are also significant at $\alpha < 0.05$. Therefore, in the LCM, the processing time with and without delay is less than the FCM and the production rate is higher in this method (Table 7).

4. Discussion

The results of the time study showed that greatest amount of time is related to chipping and residue collection at both methods. In Chipper KOREN K 17000, the inlet opening is small (0/5*0/8 m) and it can't be poured into a large volume of debris per cycle and so the chipping time will increase. Mechanical was recorded as Major delay at both methods because this chipper was designed for very thin (less than 5 cm)

Table 4. Descriptive statistics of the independent variables of regression model for the prediction of chipping time in Landing Chipping Method (LCM).

Independent variables	N	Minimum	Maximum	Mean	Std. Deviation	Skewness	Kurtosis
Distance between orchards (m)	60	0.00	1500.00	556.66	3.25	0.55	−0.98
Orchard area (ha)	60	0.50	2.00	0.87	0.49	1.53	0.76
Residues density (m^3/ha)	60	2.00	7.00	4.45	1.47	0.24	−0.38
Distance between trees (m)	60	3.00	4.00	3.71	0.45	−0.98	−1.06
Diameter (cm)	60	12.00	42.00	23.41	7.58	0.45	−0.55
Age (year)	60	8.00	20.00	13.31	4.02	0.52	−0.88

Table 5. Descriptive statistics of the independent variables of regression model for the prediction of chipping time in Farm Chipping Method (FCM).

Independent variables	N	Minimum	Maximum	Mean	Std. Deviation	Skewness	Kurtosis
Distance between gardens (m)	60	0.00	1500.00	636.66	1.69	0.33	−1.07
Orchard area (ha)	60	0.50	2.00	1.02	0.55	0.55	−1.33
Functional area (m^2)	60	40.00	200.00	95.83	1.75	1.01	0.17
Residues density (m^3/ha)	60	2.00	7.00	5.05	1.60	−0.41	−0.77
Distance between trees (m)	60	3.00	4.00	3.43	0.49	0.27	−1.99
Diameter (cm)	60	8.00	45.00	20.93	1.27	0.66	−0.96
Age (year)	60	8.00	20.00	14.85	4.66	−0.16	−1.49

Table 6. Processing time equations for LCM and FCM methods.

Methods	Equations	Standardized coefficients (beta)	Sig.	R^2
LCM method	Processing time (min)			0.77
	= 0.73 diameter of trees (cm)	0.72	0.000	
	+ 0.48 age of trees (year)	0.25	0.001	
FCM method	Processing time (min)			0.64
	= −27.41		0.009	
	+ 0.35 diameter of trees (cm)	0.25	0.005	
	+ 2.51 age of trees (year)	0.76	0.000	
	+ 3.30 residue density (m^3/ha)	0.34	0.004	
	+ 0.72 functional area (m^2)	0.19	0.022	

Table 7. Paired samples statistics, normality test, and results of the paired t-test.

				Kolmogorov–Smirnov test		Paired t-test	
Statistics	Method	Mean	N	Z	Sig.	t	Sig.
Time with delay (min)	LCM	31.06	60	0.54	0.64	−2.23	0.02
Mechanical delay(min)	FCM	41.25	60	0.36	0.09	−0.49	0.62
	LCM	1.81	60	0.64	0.92		
Personal delay(min)	FCM	2.36	60	0.59	0.85	0.08	0.93
	LCM	0.73	60	0.51	0.73		
Organizational delay (min)	FCM	0.70	60	0.66	0.96	−1.51	0.02
	LCM	0.83	60	0.43	0.29		
Time without delay (min)	FCM	1.93	60	0.59	0.33	−2.64	0.01
	LCM	32.63	60	0.70	0.47		
Production with delay (kg/min)	FCM	43.88	60	0.65	0.31	5.97	0.00
	LCM	4.23	60	0.29	0.09		
	FCM	2.32	60	0.45	0.12		
Production without delay (kg/min)						6.05	0.00
	LCM	4.56	60	0.21	0.08		
	FCM	2.47	60	0.26	0.26		

branches and leaves, while the residues from pruning apple trees are thicker, and chipping them with this chipper causes a mechanical malfunction (slackening of the blade, loosening the screws, etc.) and increasing the delay time.

The reason that residues collection in LCM was more than the second method is the lower distance between source and chipper in FCM.

Comparing the total time in both methods showed that these two methods have a significant difference and the total time in the FCM is more than the LCM. Because the LCM activities are more intensive, i.e. operations of the chipping, packing, and loading the secondary transportation machine are done at the landing location. Also, a comparison of delays showed that there is no significant differences between the two methods in terms of mechanical and personal delays, however, there are differences in terms of organizational delay. The delay is greater in the FCM than LCM In FCM, the chipper was ported by agricultural standards tractor and coordination among residues collection workers, chipper operator and the driver of the tractor is time-consuming operations.

Application of a fixed chipper in the landing was more effective in processing residues from apple trees due to lower cost and higher production rates than the mobile chipper FCM. The obtained result is in accordance with Magagnotti et al. (2013) who found that single-pass harvesting (FCM) was the cheapest, especially if applied through a dedicated tractor and a towed unit with a large integral container.

The lowest cost and the highest benefit rate were obtained in LCM and transportation with the truck. Because the transporting cost of chips by truck

(US$2.18 per ton) is less than a pickup truck (US$6.00 per ton) and trailer (US$2.5 per ton). In this study, the average transporting cost is about 25% of the total cost and the rest is spent on chipping. Torquati et al. (2016) studied tree crop pruning residues for energy purposes and showed that total costs were more than €63 per ton, whereas, 55% was spent for chipping and transport cost was 45% of the total cost. Although, the distance between farms and mill were the same in both studies, however, transport cost in our study was lower than theirs.

Effect of variables of diameter and age of trees was significant on residue processing time for LCM, however, for FCM, in addition to the diameter and age of trees, the effect of variability of residue density and functional area is significant on residue processing time. In LCM, the residues are collected and stacked on the landing. Therefore, the processing time does not correlate with residue density and functional area in each cycle, however, processing time increases with increasing diameter and age of trees. Louis and Kizha (2019) have calculated the cost of integrated harvesting of small diameter trees dominated stand using various apportioning methods and the result showed that chipping operation was depended on the diameter of the logs and the number of trees fed into the chipper.

By correctly planning and conducting studies, residues wood from pruning trees can be converted into valuable resources for particleboard industries, and in fact replace the common commercial wood used by industry. In this way, the pressure of harvesting from the commercial forests of the north of Iran will be somewhat reduced and the needs of particleboard industries will be met by alternative sources.

According to the production of more than 400,000 tons of residues from pruning of apple trees annually, the recovery of the residues will generate about $14 million ($35 per ton) and the implementation of this project involved with the employment of about 3000 people will be directly and indirectly in rural areas in Iran. Job creation in rural areas on one hand increasing the economic income of chipper producers and particleboard industries and in the other hand leads to rural economic development and sustainability of rural communities.

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