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RESEARCH ARTICLE

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Comparison of the technical and economic performances of two different shredders on pomegranate pruning residues

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Abstract

Aim of study: The study aimed to examine the technical and economic performances of two different shredders for three windrow densities of pomegranate residues.

Area of study: The study was conducted in the Serik District of Antalya Province, Turkey.

Material and methods: Two different pruning residue shredders driven by tractor power take off (PTO) were used. Machine-I has pickup, shredding, screen units. Machine-II only has a shredding unit. The experiment was conducted at windrow densities of 1.49, 2.10, and 2.41 kg/m^2 in a pomegranate orchard; the study used a completely randomized split-plot design with two treatments and three replications.

Main results: The power values for the increasing windrow densities were 8.00, 11.73, and 18.47 kW/m for Machine-I and 5.08, 5.68, and 6.48 kW/m for Machine-II. Moreover, the average particle length of 68.6 mm shredded by Machine-I was approximately 20 mm smaller than that of Machine-II. The minimum unit energy value of Machine-II was 2.53 kWh/t at the maximum windrow density of 2.41 kg/m^2. This value for Machine-I was 5.58 kWh/t at the medium windrow density of 2.10 kg/m^2. The lowest unit cost for Machine-I and Machine-II was calculated as 27.2-7.1 US$/t (at medium density) and 16.8-3.5 US$/t (at maximum density), respectively.

Research highlights: The appropriate windrow densities for Machine-I and Machine-II were different in terms of energy requirements and total unit cost. Machine-I is more effective at consistently chopping the residues than Machine-II, but it requires more energy and a higher unit cost.

Additional key words: chopping; power and energy; particle length; machinery costs; *Punica granatum*.

Abbreviations used: PTO (power take off). **Nomenclature:** C_d (annual average depreciation, US$/year); C_f (fuel cost, US$/h); C_i (cost of interest, US$/year); C_{rm} (cost of repair and maintenance, US$/h); FC_s (specific fuel consumption, L/kWh); f_i (number of parts in each group -the frequency, unit); f (number of parts, unit); h (accumulated use of machine, h); i_r (reel interest rate, decimal); LR (load ratio of tractor during the working, decimal); N (economic life of the machine, year); P (purchase price, US$); P_f (price of fuel, US$/L); P_t (tractor power, kW); RF1-RF2 (repair and maintenance factors, decimal); S (salvage value, US$); X_{avr} (average particle sizes, mm); X_i (group's particle sizes, ... mm)

Authors' contributions: The two co-authors participated in all stages of the work, including the conception and design of the research, performance of the experiments/material support, analysis/interpretation of the data, revision of the intellectual content and drafting of the paper.

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Introduction

Fruit production has an important place in among the agricultural cultivation branches. Unlike other agricultural crops, fruit trees, are perennial plants, and they should be pruned either every year or within a few years to increase the quality and quantity of production. Subsequently, a residual woody biomass is obtained depending on the tree's properties such as its structure and pruning frequency. These agricultural operations require disposing of the residues; otherwise, they become an obstacle to the other cultivation processes

(Velázquez-Martí *et al.,* 2012). After these operations are completed, the obtained ligneous residues are either eliminated by burning them outside the orchard or by using them in many different ways such as mulch, biomass, etc. Burning the remains generate toxic air pollutants and has an impact on global climate change (Goncalves *et al.*, 2011). Consequently, the government in some countries may restrict the burning processes (Holtz *et al.*, 2005). Thus, pruning residues plays an essential ecological and economic resource role in today's world (Fedrizzi *et al.*, 2012).

The residues should be evaluated based on different properties, such as farm sizes, cultivation methods, regional characteristics, technology usage, costs etc. Residues can be used as mulch on the ground or mixed into soil. They are also utilized as raw materials for power and industrial plants (Ntalos & Grigoriou, 2002; Velazquez-Marti *et al.*, 2011; Fedrizzi *et al.*; 2012, Spinelli *et al.*, 2012, Velazquez-Marti *et al.,* 2012; FernandezSarria *et al.*, 2019). Regardless of the method that is used, the size of the residue has to be reduced by shredding it. For mulching purposes the shredded residues can either be recycled on site, or removed from the orchards and then transported to processing plants (Spinelli & Picchi, 2010; Velazquez-Marti *et al.*, 2011). Some studies have pointed out that the pruned residues are collected and baled without reducing their size and they are then transported to power and industrial plants before being shredded (Savoie *et al.*, 2008; Spinelli *et al.*, 2010, 2014). Usage of the pruned residue as biomass for energy production, in boilers or as raw material in some industrial plants requires specific processes or technologies. For this purpose, many studies focusing on different pruning residues have been conducted in different countries. Currently, many machines have been designed (Recchia *et al.*, 2009; Damour & Lavoie, 2010; Fedrizzi *et al.*, 2012; Spinelli *et al.*, 2014; Manzone, 2016), different machines and technologies have been compared in terms of management (Savoie *et al.*, 2008; Spinelli *et al.*, 2010; Do Canto *et al.*, 2011) and some logistics model have been developed (Spinelli & Magagnotti, 2010; Ghaffariyan *et al.*, 2013; Magagnotti *et al.*, 2013). These studies primarily concentrated on woody residues especially in Mediterranean countries.

Spreading residues into the soil or mulching them could be a good solution, especially for regions that do not have technological infrastructures for energy production and a market for woody residues, or those that do not have enough organic matter in their soil. These two applications could be defined as being more practical and simpler than the other methods. Shredded pruning residues increase the organic matter content, which improves some of the physical and chemical characteristics of soil, such as its water holding capacity, humic content, nutrient adsorption capacity, pH buffering capacity and microbial diversity (Holtz *et al.*, 2005). Moreover, the residues are used to protect the soil from erosion; thus, these applications are becoming a common practice in sustainable agriculture (Calatrava & Franco, 2011; Jimenez *et al.*, 2013; Manzanares *et al.*, 2017). Therefore, many farmers in different countries prefer the aforementioned techniques. Calatrava & Franco (2011) pointed out that the use of pruning residues as mulch has been adopted by 43% of the surveyed farmers in the olive orchards of a southern province in Spain. Çanakcı (2014) stated that since the 2000's utilization of the residues on-site, instead of burning, has begun to increase in Turkey, which has a total fruit orchard area of more than 3.3 million ha that is increasing every year (Turkish Statistical Institute, www.tuik.gov.tr). Adamchuk *et al.* (2016) stated that these applications are required to reduce energy and labor consumption, but and to lower of the demand for mineral fertilizers, which will significantly improve the ecological indices of the natural environment in Russia, Ukraine and Armenia.

Some studies focused on different pruning residues in different countries. Holtz *et al.* (2005) investigated the effect of almond pruning residues on soil and petiole nutrients, soil aggregation, water infiltration, and nematode and basidiomycete populations. Repullo *et al.* (2012) studied the capacity of different pruning residue applications on olive orchard lanes to increase carbon content. Yilmaz *et al.* (2017) examined the effects of the application of vine pruning residue on soil properties and productivity under Mediterranean climate conditions in Turkey. Significant developments were observed in terms of the organic matter content of soil and various plant macro nutrient elements, especially phosphorus and nitrogen.

For each pruned material utilization methods, the process should be done with appropriate machines, systems, or organizational planning in terms of work quality and costs. Studies related to the machines that use the remains as feedstock material in energy or industrial plants have been conducted in many countries. Hovewer, there are a limited number of studies on machines that are used to chop pruning residues to create mulching or provide organic matter to the soil. For instance, Çanakcı *et al.* (2010) aimed to determine basic management data of power take off (PTO) driven pruning residue shredder on different pruned residues obtained from grapes (vineyards), and pomegranate, and orange, and avocado orchards. Moreover Dereli & Çakır (2014) determined the cutting performance of different shredders used in vineyards for chopping after pruning. Adamchuk *et al.*, (2016) studied how to increase the chopping and spreading of pruning residue to develop a new wood shedder design.

Today, although different shredders can be used, hanging or semi-hanging shredders driven by PTO are commonly manufactured and used in orchards in many countries. It is very important to know some of the parameters of the machines, such as the size of the shredded particle, the power requirements, the energy consumption per shredded mass, and the usage costs, and to compare the selection and usage stages of these machines in terms of work efficiency and biomass management. This management data is very useful for planners, consultants, designers, manufacturers and farmers. Thus, the present study aimed to compare and contrast the technical and economic performance of two different shredders driven by PTO in order to improve soil properties.

Material and methods

The PTO power, area and material capacity, unit energy, particle length and machinery cost values of two shredders were determined and compared in terms of their technical and economic performance. An orchard experiment was conducted to obtain basic operational parameters such as PTO torque, PTO revolution, forward speed and residue densities.

The main material of the study consists of two shredders, Machine-I and Machine-II manufactured in Turkey (Ersun Agricultural Machinery Company, Tekirdağ City) driven by tractor PTO. Both machines chopped the pruning residues, which were formed as a windrow, and left the residues on the soil surface.

Machine-I was a combined machine and it had pickup, shredding and screen units. The motion from the PTO to a gear box placed on the chassis was transmitted to the pick-up and shredding units using double-side output. A total of 18 fingers were placed in 4 rows on the rotor of the pick-up unit, which picks up the pruned residue materials from the windrow and transfers them to the shredding chamber. The basic parts of the shredding unit consist of a rotor and 18 flail blades placed in the rotor. The blade type, also called a universal blade, consists of three free parts, two L-shaped blades located opposite of each other and one straight blade in the middle. The blades are made of alloyed steel material of 30 Mn5 (DIN EN 10083 3: 3006) and the total weight of one blade group is 1730 g (Fig. 1a). The screen forms the lower part of the shredding chamber. A steel cover was placed on the chassis to constitute the upper part of the chamber. During the experiments, the screen unit with 36 mm holes was used. The experiment started with the brand new/unused blades on both machines. While operating the machine, the chopped materials passing through the holes were left on the soil surface. During the chopping operation, the machine was carried by a supporting rear tire. The second machine, Machine-II, only has a shredding unit (Fig. 1b). A cylindrical roller was placed at the rear of the machine instead of a supporting tire. Machine-II had 18 blades; the revolution of the blades was 1827 rev/min (in the PTO revolution, 540 rev/min), and the working width was 1.70 m. The total weight of the machines was 800 kg (Machine-I) and 530 kg (Machine-II).

The experiment took place in a 15-year-old pomegranate (*Punica granatum* cv. Hicaz) orchard located in the Serik District of Antalya Province in Turkey. The average thickness and the moisture values of the residues were measured as 17 mm and 28.5% wet basis (w.b.). In the orchard, the spacing within each row and between the rows was 4 × 4 m. The residues were shredded by passing each row once time. Hence, the machine working width of both machines was 4 m. Prior to the experiment, only one gear stage was found to be appropriate as the eligible operating speed; thus the pruning residues were chopped at one forward speed of 1.5 km/h. The machines could not be operated at higher speeds, because the time required for shredding was limited to the forward speed in the trial conditions. Generally, higher speeds, such as 1.8 km/h to 2.0 km/h, cause blockages, while lower speeds reduce the machine's capacity. Both machines were driven by a New Holland TD 75 D tractor with a 55.2 kW engine power.

The experimental study was arranged in a completely randomized split-plot design with two treatments and three replications. The main treatments include two machines (Machine-I and Machine-II) and three windrow densities (1.49, 2.10 and 2.41 kg/m^2-wet base) arranged in lengths of 30 m plots.

Before the experiment, regular windrows were formed manually. To determine the minimum density (D1), the amount of material that provides continuity on the windrow that is too little to cause interruption was considered. The maximum density (D3) was determined based on the machine's density level. The other density (D2) is a value between the other specified quantities. The values of the average sizes were calculated from 10 different points. The average windrow width and high values were found to be 136-28 cm, 142-36 cm, and 155-42 cm for the D1, D2 and D3 windrow densities, respectively.

A measuring system was used to determine PTO torque, PTO power and rotational speed. It consists of a torque meter mounted to the PTO output (Datum Electronics Company, Series 420, Isle of Wight, UK)

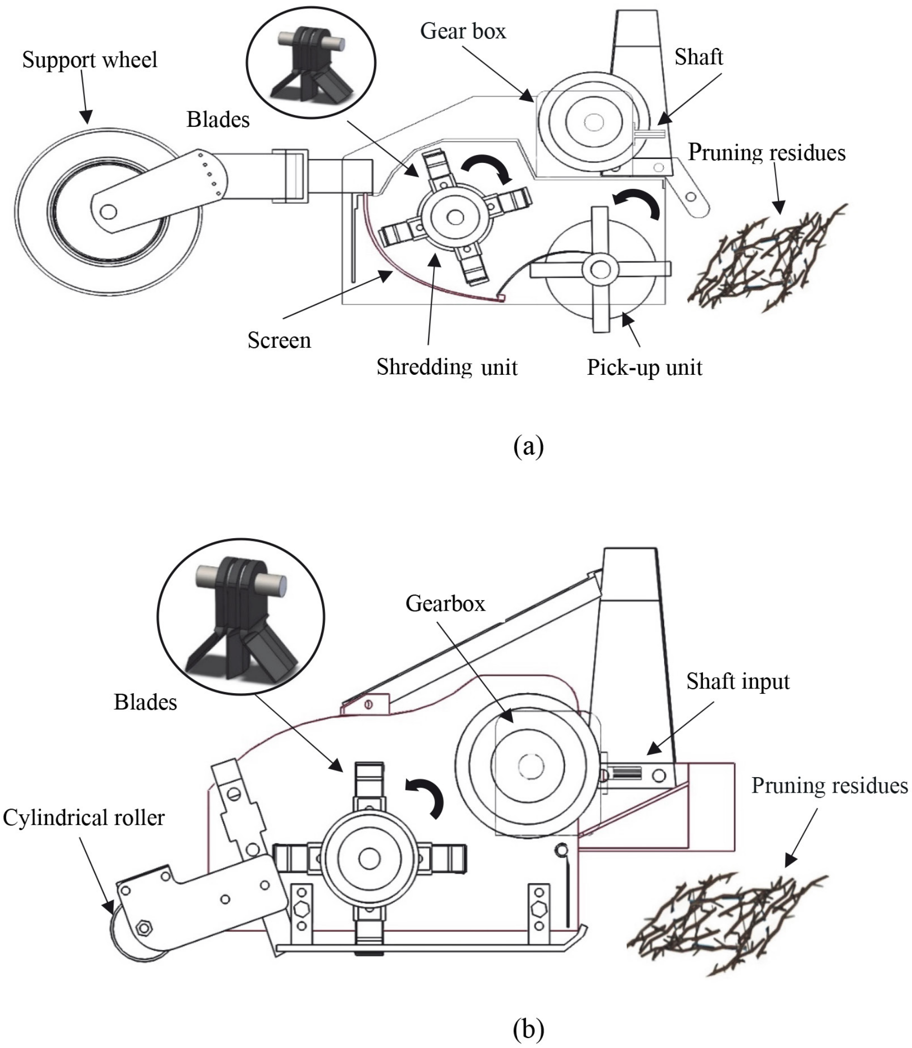

Figure 1. Schematic views of Machine-I (a) and Machine-II (b).

with a capacity of 1800 Nm and an accuracy of 0.5%; this system has its own software. When operating the machine, the measured torque (Nm), rotational speed (min^{-1}), calculated PTO power (kW), and elapsed time values can be monitored in real time. Data can be saved as a file of the desired frequencies in the measuring system. In this study, the mentioned data were recorded at 1 s intervals.

During the experiments, time consumption was measured with a chronometer through the plot length of 30 m, and the forward speed was calculated. Both machines chopped the pruning residues at a speed of 1.5 km/h. This value is equal to or very close to other speed values calculated with similar material (Çanakcı *et al.*, 2010; Fedrizzi *et al.*, 2012; Velázquez-Martí *et al.*, 2012).

Area (ha/h) and material capacities (t/h) were calculated using forward speed, the orchard's row spacing, field efficiency, and densities of residue per unit area. The field efficiency was taken as 85% based on the findings reported in other similar studies (Çanakcı *et al.*, 2010; Fedrizzi *et al.*, 2012). The working width of both machines was taken as 4 m, since the shredders only passed in the middle of the two rows, once. The energy requirement per unit mass (kWh/t) was calculated by dividing the required power during the shredding operations by the material capacity values.

The particle lengths were considered to compare particle size distributions. Samples of the chopped material were collected from each of the plots. For this purpose, an iron frame (1×1 m) placed in each plot was used, then all of the remaining materials inside the frame were collected for analysis. A total of 11 frequencies with the unit of mm (<30, 31-60, 61-90, 91-120, 121-150, 151-180, 181-210, 211-240, 241-270, 271-300, >300) were considered to determine the average particle length and to compare the two shredders. A digital caliper with an accuracy of 1% was used to measure the length of the shredded particles. The average particle size of the measured values was calculated using the following equation (Şeflek *et al.*, 2006; Demir, 2007; Kaplan, 2007).

$$X_{avr} = \frac{\sum f_i \cdot x_i}{\sum f} \quad [1]$$

where X_{avr} is the average particle size, mm; x_i is the group's particle size, mm; f_i is the number of parts in each group -the frequency, unit; and f is the total number of parts, unit.

The obtained data were analyzed by using SPSS 17.0 statistical software. Where appropriate, the mean separations among the treatments determined using by Duncan test.

To evaluate economic impact, the machinery costs were calculated. The total cost for a machine was divided into two categories: ownership costs and running costs. Ownership costs, often called fixed costs are dependent on the duration of ownership of a machine: these include depreciation, interest, taxes, housing and insurance. The total cost of the other ownership components, including taxes, housing, and insurance, were accepted as 2% of the purchase price (ASABE, 2015). The equations used to determine depreciation and interest are shown below (Sayın & Özgüven, 1995; Witney, 1996).

$$C_d = \frac{P - S}{N} \quad [2]$$

where C_d is the annual average depreciation, US$/year; P is the purchase price, US$; S is the salvage value, US$; and N is the economic life of the machine, year.

$$C_i = i_r \frac{P + S}{2} \quad [3]$$

where C_i is the cost of interest, US$/year; and i_r is the reel interest rate, decimal.

The running costs (variable costs) vary directly with the amount of usage; they consist of fuel, oil, repair maintenance and labor. The equation used to calculate the cost of fuel (Işık *et al.*, 1988; Sayın & Özgüven, 1995) was:

$$C_f = P_t \cdot LR \cdot FC_s \cdot P_f \quad [4]$$

where C_f is the fuel cost, US$/h; P_t is the tractor power, kW; *LR* is the load ratio of the tractor during the operation, decimal; *FCs* is the specific fuel consumption, L/kWh; and P_f is the price of fuel, US$/L.

Oil cost was taken as 15% of the fuel cost (Evcim, 1990). The equation to calculate the repair and maintenance cost (ASABE, 2015) was:

$$C_{rm} = \left(RF1\right) \cdot P \cdot \left[\frac{h}{1000}\right]^{RF2} \quad [5]$$

where C_{rm} is the cost of repair and maintenance, US$/h; *RF1* and *RF2* are, respectively, the repair and maintenance factors, decimal; and *h* is the accumulated use of machine, h.

The labour cost and the other data used in the equations were calculated by considering the field experiment and Turkish market conditions.

Results and discussion

Power requirements, particle lengths and unit energy consumptions

The values of the average PTO powers per working machine width, shredded particle lengths and energy consumption per unit mass measured for both machines in the experiment are given in Table 1. The indicated average values determined for three different windrow densities are also shown in Table 1.

Table 1. Average PTO power, particle lengths and energy consumption values of the machines and for different windrow densities

Machines	Average PTO power, kW/m	Average particle length, mm	Average energy consumption per unit mass, kWh/t
Machine-I	12.73 ± 1.92 a*	68.58 ± 1.60 a	6.08 ± 0.31 a
Machine-II	5.75 ± 0.47 b	87.74 ± 2.84 b	3.03 ± 0.31 b
p	<0.001	<0.001	<0.001
Windrow density, kg/m²			
1.49	6.54 ± 0.79 a*	77.97 ± 4.69	4.76 ± 0.54
2.10	8.71 ± 1.39 b	78.73 ± 4.90	4.20 ± 0.64
2.41	12.47 ± 2.72 c	79.28 ± 4.50	4.70 ± 0.99
p	<0.001	0.940	0.216

* Different letters within a column denote significant differences

Both machines shredded the pruning residues collected from at distance of 4 m between two rows. Machine-I consumed more power (120%) than Machine-II. The power values between the two machines were significantly different (p<0.001). The average power was 5.75 kW/m for Machine-II; it was 12.73 kW/m for Machine-I. Machine-I requires more power due to its pick-up unit, screen unit, and shredding unit. Windrow densities have significant effects on the PTO power consumption (p<0.001). Increasing the windrow density from 1.49 to 2.41 kg/m^2 caused increases in the average power from 6.54 to 12.47 kW/m (Table 1). Moreover, it was concluded that the effect of machine×density interaction was significant for power consumption (p<0.001). The power requirements for the different residual densities for are shown in Fig. 2.

As seen in Fig. 2 the power values increased from 8.00 to 18.47 kW/m in Machine-I; these values were lower and more stable (5.08-6.48 kW/m) in Machine-II. The variance analysis results showed that, while there were significant differences among the power values of Machine-I at different windrow densities (p<0.001), there was no significant difference among the power values of Machine-II. It can be said that the residual materials were picked up and shredded in a more controlled manner by the pick-up and sieving units on Machine-I. In Machine-I, the pruned residues, taken into the chopper chamber, must be disintegrated until they pass through the screen holes in order to be left on the soil surface. Thus, the shredding time increased with increasing windrow densities at the same working speed. Dropping the chopped material from the shredding chamber became more difficult as the windrow density increased; therefore more power was to complete the shredding operation. In the experiments, no clogging was seen. However, if the machine would have worked in higher windrow densities and with the same tractor speed, some clogging might have occurred.

The average lengths of the material chopped by Machine-I and Machine-II were 68.58 mm and 87.74 mm, respectively, which is a significant difference (p<0.001). In terms of particle mean values, there was a difference of about 20 mm between the two machines; Machine-I chopped the pruning residues into size that were about 25% smaller than Machine-II. The regular transfer of the residues from the windrow to the shredding chamber followed by chopping of the brush in a more controlled way caused smaller particle lengths in Machine-I. The average length values at three different windrow densities (Table 1) were 77.97, 78.73 and 79.28 mm for both machines; no significant difference was observed (p=0.940). We also found no machine × density interaction for particle lengths.

The length of the chopped material for each machine at different windrow densities are given in Fig. 3. Figure 4 shows some pictures of the chopped pruning residues for both machines at different windrow densities.

As seen in Fig. 3, the particle lengths ranged from 68.80 to 70.37 mm in Machine-I and from 87.13 to 88.19 mm in Machine-II. Correct realization of the main processes such as picking the residues from the windrow, and chopping and spreading them to the soil surface, increases the work efficiency. The probability of achieving mentioned operations was higher in Machine-I, which has a pick-up unit and a screen unit, than Machine-II. The sizes and the distribution of the particles should be considered when comparing the two machines. The first average particle size can be more acceptable in terms of decomposing in the soil. For

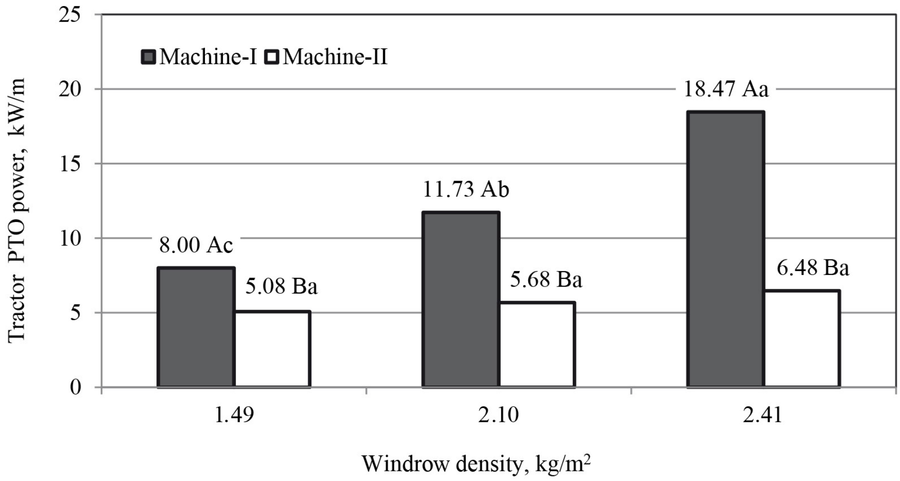

Figure 2. PTO power requirements per working machine width. The different upper and lower case letters above the histogram bars indicate significant differences (p<0.001, Duncan test) between the machines and the windrow densities, respectively.

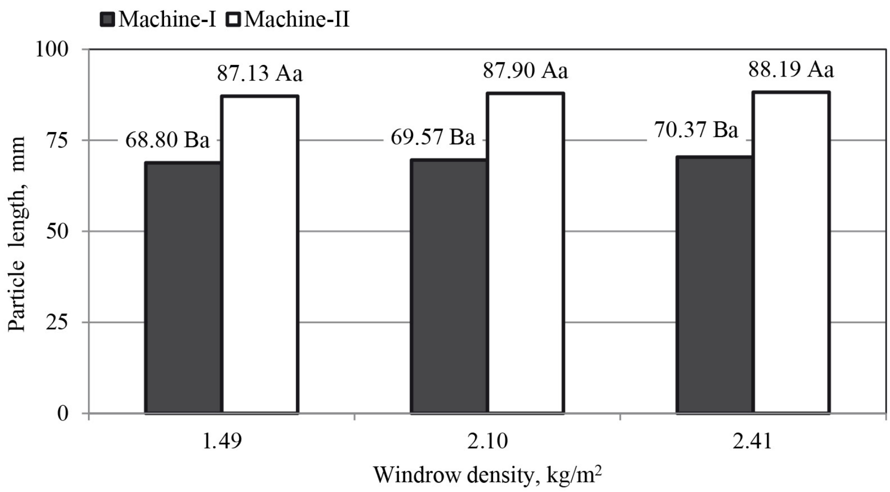

Figure 3. Lengths of the average particles. The different upper case letters above the histogram bars denote significant differences between the machines (p<0.001). The same lower case letters above the histogram bars denote non-significant differences among windrow densities at a probability of p<0.05.

Machine-II, some problems such taking the residue material into the shredding unit and the irregular distribution of the particles to the soil surface, were seen during the trials (Fig. 4). A particle size of 1-3 inches (2.54-76.2 mm) was recommended to increase the surface area of the material that is to be composted and contacted with microbes (Goldstein & Diaz, 2010). The average values of Machine-II remained outside the upper limit of 76.2 mm. Moreover, these materials were not distributed homogeneously (Fig. 4). Since Machine-II collects residues by sweeping, regular residue feeding could not be observed; sometimes, this was because feeding the material into the shredder was prevented during the field experiments. In this case, it may be advisable to add a pick-up unit as seen in the machine developed by Adamchuk *et al.* (2016).

The unit energy consumption values were calculated as kWh/t. The field capacity for both machines was 0.51 ha/h ([1.5 km/h×4 m×0.85]/10). Considering the windrow densities and the field capacity value, the machine capacities used to determine energy consumption for unit mass were calculated as 1.50, 2.72 and 3.40 t/h, respectively.

MachineI needed more power than Machine-II in terms of per unit shredded mass. The pick-up and screen units in Machine-I affected the energy consumption, similar to power values. The effects of the different machines on energy consumption per unit mass were

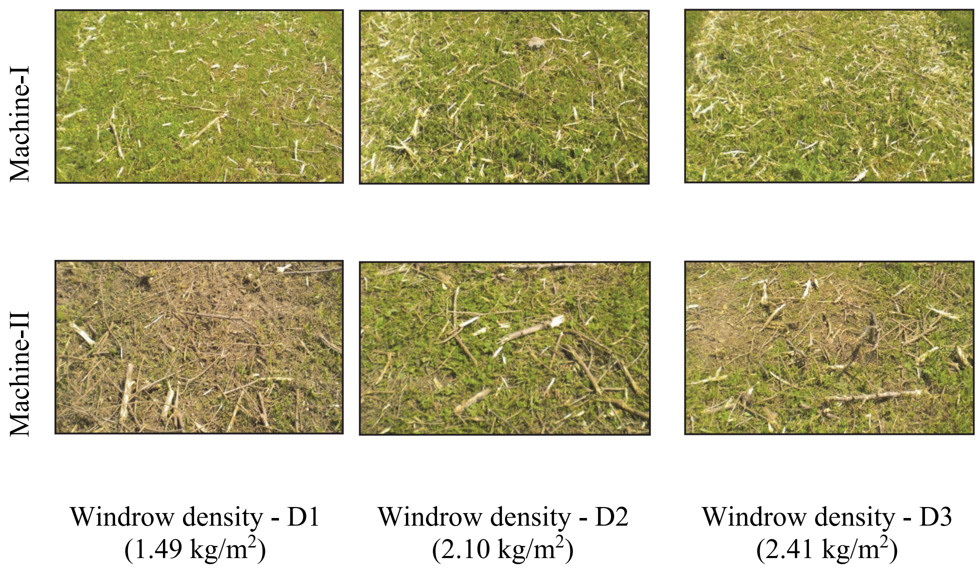

Figure 4. Views of the shredded residues with different windrow densities.

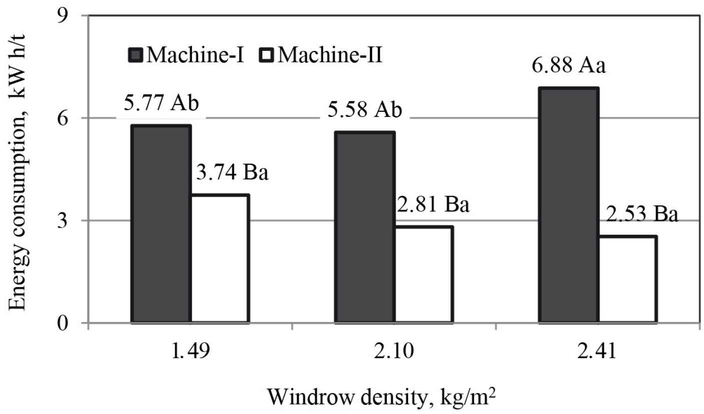

Figure 5. Energy consumption values per unit of shredded residue. The different upper case letters above the histogram bars denote significant differences between the machines at $p<0.001$. The different lower case letters above the histogram bars denote significant differences between windrow densities ($p<0.05$).

found to be significant ($p<0.001$) (Table 1). However, different windrow densities did not significantly affect the average energy consumption per unit mass ($p=0.216$). For the D1 windrow density, the average energy consumption per unit mass value of 4.76 kWh/t decreased to 4.20 kWh/t for D2 and then increased again to 4.70 kWh/t for D3 (Table 1). According to the statistical analysis, the effect of the interaction between the machine and windrow density was significant for the energy power consumption in per unit mass ($p<0.001$). Energy consumption values for the machines at different windrow densities are shown in Fig. 5.

The energy consumption values for the windrow densities ranged from 5.77 to 6.88 kWh/t for Machine-I and from 2.53 to 3.74 kWh/t for Machine-II. According to the variance analysis results, although there were significant differences among the energy requirement values of Machine-I ($p<0.05$), no significant differences were obtained for Machine-II (Fig. 5).

The energy consumption per unit shredded mass material is an important value in terms of management. This data can help machine users determine the optimum windrow density. As seen in Fig. 5, the energy consumption per shredded mass decreased as the windrow density increased for Machine-II. For Machine-I, this value tended to decrease from D1 to D2, and it increased rapidly for D3. Considering that the difference between the average particle lengths for Machine-II was insignificant, it can be suggested that the D3 windrow density (2.41 kg/m^2) is more suitable for this machine due to the minimum unit energy consumption. Similarly, the appropriate windrow density for Machine-I was found for D2 windrow density (2.10 kg/m^2).

In comparison, Machine-I, which had same type of blades as Machine-II, has an advantage in terms of the ability to produce smaller chopped particles. However, although Machine-I does a better job of shredding the residues, it consumes more power. Most farmers prefer Machine-II due to its simple structure and lower costs. In this circumstance, some extra work may be needed for Machine-II to make it easier to take the residues to the shredding unit and obtain smaller and regular sized particles. Some studies aimed to decrease the power requirements and reduce the particle sizes of shredders that are similar to Machine-II (Dereli & Çakır, 2014; Adamchuk *et al.*, 2016). However, studies are needed to investigate how to decrease power consumption for the shredders in Machine-I.

Machinery costs

The fixed and variable costs of the machines are shown in Table 2 and Table 3, respectively.

Table 2. Fixed costs of the machines

Machines	Purchase price, US$	Depreciation, US$/yr	Interest, US$/yr	Tax, housing, insurance, US$/yr	Total fixed cost, US$/yr
Machine-I	5526	461.4	114.6	110.5	686.6
Machine-II	2895	241.7	60.1	57.9	359.7

Table 3. Machinery variable and total unit costs

Machines	Windrow density, kg/m^2	Fuel and oil		Repair and maintenance		Labour		Total variable cost		Total unit cost*	
		US$/h	US$/t	US $/h	US$/t	US$/h	US$/t	US$/h	US$/t	US$/h	US$/t
Machine-I	1.49	12.3	4.8	2.0	0.8	4.1	1.6	18.4	7.2	21.9	8.5
	2.10	17.6	4.6	2.0	0.5	4.1	1.1	23.7	6.2	27.2	7.1
	2.41	27.1	5.7	2.0	0.4	4.1	0.9	33.2	7.0	36.6	7.7
Machine-II	1.49	8.0	3.1	1.1	0.4	4.1	1.6	13.2	5.1	15.0	5.8
	2.10	8.9	2.3	1.1	0.3	4.1	1.1	14.1	3.7	15.8	4.2
	2.41	9.9	2.1	1.1	0.2	4.1	0.9	15.1	3.2	16.8	3.5

*The annual usage of the machines was considered to be 200 h

The purchase price of the machines directly affects the fixed costs, and they are calculated annually. As seen in Table 2, these values were 686.6 US$/yr and 359.7 US$/yr for Machine-I and Machine-II, respectively. Annual costs can be converted into unit cost values by dividing these values into the yearly usage values such as hours and area.

The estimated life of these machines is determined as 2000 hours and 10 years (ASABE, 2015). If the machines were used for 200 h/yr, the hourly fixed costs can be defined as 3.4 US$/h and 1.8 US$/h for Machine-I and Machine-II, respectively. Increased use of machine within a year will reduce the fixed cost per hour or vice versa.

As expected, the variable costs were higher for Machine-I than Machine-II, the cost per usage time ($/h) increased with increasing windrow densities. The largest share of variable costs consisted of the fuel and oil costs. In terms of the unit of US$/t, the variable costs are expected to decrease as the windrow density increases (Table 3). These values decreased from 5.1 US$/t to 3.2 US$/t for Machine-II; for Machine-I, they first decreased from 7.2 US$/t (D1) to 6.2 US$/t (D2) and then increased to 7.0 US$/t (D3).

Total unit costs were calculated by considering the annual machine usage of 200 hours. These costs per hour increased based on the windrow densities; they ranged from 21.9 US$/h to 36.6 US$/h and 15.0 US$/h to 16.8 US$/h for Machine-I and Machine-II, respectively. The minimum total unit cost per shredded residual mass was 7.1 US$/t for the D2 windrow density (2.10 kg m^{-2}) for Machine-I; it was 3.5 US$/t for the D3 windrow density (2.41 kg/m^2) for Machine-II.

As noted in the unit energy consumption, excess pruning residue in the shredding chamber greatly increases the power requirement for Machine-I. This causes the highest energy consumption in the D3 and it has a negative effect on to the total unit cost. Therefore, in terms of both energy requirements and total unit costs, the appropriate windrow densities for Machine-I and Machine-II were different. Machine-I is more effective at consistently chopping the biomass material than MachineII, but it requires more energy and higher unit costs.

In conclusion, technical and economic performance data were obtained for two different residue shredders driven by tractor PTO while working with pruned pomegranate branches. Significant differences were found the performances of the machines. These data were determined under practical conditions, so they can be beneficial for farmers, contractors, researchers and manufacturers. To ensure better machine performances, studies needed to determine how to decrease power consumption for Machine-I and increase chopping efficiency of Machine-II.

References

Adamchuk V, Bulgakov V, Skorikov N, Yezekyan T, Olt J, 2016. Developing a new design of wood chopper for grape vine and fruit tree pruning and the results of field testing. Agron Res 14 (5): 1519-1529.

ASABE, 2015. Agricultural machinery management data. Am Soc Agr Biol Eng Standards, ASAE D 497.7 MAR 2011 (R2015).

Calatrava J, Franco JA, 2011. Using pruning residues as mulch: Analysis of its adoption and process of diffusion in Southern Spain olive orchards. J Environ Manage 92: 620-629. https://doi.org/10.1016/j.jenvman.2010.09.023

Çanakcı M, Topakcı M, Ağsaran B, Karayel D, 2010. Determination of basic machinery management data for PTO driven pruning residue chopper. J Agr Sci 16: 46-54 [in Turkish].

Çanakcı M, 2014. Shredding of pruning residues and its mechanization. Harvest Journal - Plant Production. Hasad Dergisi - Bitkisel Üretim 29 (344):70-78. [in Turkish].

Damour L, Lavoie F, 2010. Anderson introduces a new biomass baler. CIGR XVIIth World Congress, CSBE101656, Jun 13-17. Québec, Canada.
Demir O, 2007. The determination of performance values of stubble chopper. MSc, Selçuk University, Graduate School, Nat Appl Sci Dept Agr Machin, Konya, Turkey, 55 p. [in Turkish].
Dereli İ, Çakır E, 2014. Development and determination of the field performance of stalk choppers equipped with different blade configurations. Bulg J Agr Sci 20 (5): 1273-1276.
Do Canto JL, Klepac J, Rummer B, Savoie P, Seixas F, 2011. Evaluation of two round baling systems for harvesting understory biomass. Biomass Bioenergy 35: 2163-2170. https://doi.org/10.1016/j.biombioe.2011.02.006
Evcim HÜ, 1990. Database on agricultural mechanization management and its planning. Ege Univ., Fac. of Agric., Publ. 495, İzmir, Turkey. [in Turkish].
Fedrizzi M, Sperandio G, Pagano M, Pochi D, Fanigliulo R, Recchi P, 2012. A prototype machine for harvesting and chipping of pruning residues: first test on hazelnut plantation (Corylus avellana L.). Int Conf of Agr Eng, CIGR-Ageng, July 8-12, Valencia, Spain.
Fernandez-Sarria A, Lopez-Cortes I, Estornell J, Velazquez-Marti B, Salazar D, 2019. Estimating residual biomass of olive tree crops using terrestrial laser scanning. Int J Appl Earth Obs Geoinformation 75:163-170. https://doi.org/10.1016/j.jag.2018.10.019
Ghaffariyan MR, Spinelli R, Brown M, Mirowski L, 2013. Chipping model: a tool to predict the productivity and cost of chipping operations. AFORA (Australian Forest Operations Research Alliance). Indust Bull 4. https://pdfs.semanticscholar.org/208c/93ccd96ddb5214b7a555b5aa20eba0751011.pdf [13 Feb 2020].
Goldstein N, Diaz LF, 2005. Size reduction equipment review. BioCycle January. https://www.biocycle.net/2005/01/21/size-reduction-equipment-review/ [13 Feb 2020]
Goncalves C, Evtyugina M, Alves C, Monteiro C, Pio C, Tome M, 2011. Organic particulate emissions from field burning of garden and agriculture residues. Atmosph Res 101: 666-680. https://doi.org/10.1016/j.atmosres.2011.04.017
Holtz BA, Caesar-TonThat T, McKenry MV, 2005. Wood chipping almond brunch and its effect on soil and petiole nutrients, soil aggregation, water infiltration, and nematode and basidiomycete population. Opt Méditerr Sér A 63: 247-254.
Işık A, Sabancı A, Ağanoğlu V, 1988. Evaluation of the efficient factors for purchasing and renting prices of the agricultural machinery in the Çukurova Region. Proc Nat Congr on Agric Mechaniz, pp: 114-123, Erzurum; Turkey. [in Turkish].
Jiménez-Jiménez F, Blanco-Roldán GL, Márquez-García M, Castro-García S, Agüera-Vega J, 2013. Estimation of soil coverage of chopped pruning residues in olive orchards by image analysis. Span J Agric Res 11 (3): 626-634. https://doi.org/10.5424/sjar/2013113-3742
Kaplan F, 2007. A research based on the cutting of cotton stalk and mixed to eart. MSc, Harran Univ, Graduate School of Nat Appl Sci, Dept Agr Machin, Şanlıurfa, Turkey, 60 pp. [in Turkish].
Magagnotti N, Pari L, Picchi P, Spinelli R, 2013. Technology alternatives for tapping the pruning residue resource. Bioresour Technol 128: 697-702. https://doi.org/10.1016/j.biortech.2012.10.149
Manzanares P, Ruiz E, Ballesteros M, Negro NJ, Gallego FJ, López-Linares JC, Castro E, 2017. Residual biomass potential in olive tree cultivation and olive oil industry in Spain: valorization proposal in a biorefinery context. Span J Agric Res 15 (3): e0206. https://doi.org/10.5424/sjar/2017153-10868
Manzone M, 2016. A bundler prototype for forestry and agricultural residue management for energy production. Int J Forest Eng 7 (2): 103-108.
Ntalos GA, Grigoriou AH, 2002. Characterization and utilisation of vine prunings as a wood substitute for particleboard production. Ind Crops Prod 16: 59-68. https://doi.org/10.1016/S0926-6690(02)00008-0
Recchia L, Daou M, Rimediotti M, Cini E, Vieri M, 2009. New shredding machine for recycling pruning residuals. Biomass Bioenergy 33: 149-154. https://doi.org/10.1016/j.biombioe.2008.05.003
Repullo MA, Carbonell R, Hidalgo J, Rodriguez-Lizana A, Ordonez R, 2012. Using olive pruning residues to cover soil and improve fertility. Soil Till Res 124: 36-46. https://doi.org/10.1016/j.still.2012.04.003
Savoie P, Lavoie F, Damours L, 2008. Modified round baler to harvest small-diameter woody biomas. J Agric Machin Sci 4 (4): 365-370.
Sayın S, Özgüven F, 1995. A study on calculation of the manufacturing ond operating costs of agricultural machines that are widely used in Turkey. Proc Nat Congr Agric Mechan, pp: 585-594, Bursa, Turkey. [in Turkish].
Şeflek Y, Çarman K, Özbek O, 2006. Investigation of the performance values of machine using in chopping of pruning redisues, J Agric Machin Sci 2 (3): 219-224 [in Turkish].
Spinelli R, Magagnotti N, 2010. A tool for productivity and cost forecasting of decentralised wood chipping. For Policy Econ 12: 194-198. https://doi.org/10.1016/j.forpol.2009.10.002
Spinelli R, Picchi G, 2010. Industrial harvesting of olive tree pruning residue for energy biomass. Bioresour Technol 101: 730-735. https://doi.org/10.1016/j.biortech.2009.08.039
Spinelli R, Magagnotti N, Nati, C, 2010. Harvesting vineyard pruning residues for energy use. Biosyst Eng 105: 316-322. https://doi.org/10.1016/j.biosystemseng.2009.11.011
Spinelli R, Nati, C, Pari L, Mescalchin E, Magagnotti N, 2012. Production and quality of biomass fuels from mechanized collection and processing of vineyard pruning residues. Appl Energ 89: 374-379. https://doi.org/10.1016/j.apenergy.2011.07.049
Spinelli R, Lombardini C, Pari L, Sadauskiene L, 2014. An alternative to field burning of pruning residues in mountainvineyards. Ecol Eng 70: 212-216. https://doi.org/10.1016/j.ecoleng.2014.05.023
Velázquez-Martí B, Fernández-González E, López-Cortés I, Salazar-Hernández, DM, 2011. Quantification of the re-

sidual biomass obtained from pruning of trees in Mediterranean olive groves. Biomass Bioenergy 35: 3208-3217. https://doi.org/10.1016/j.biombioe.2011.04.042

Velázquez-Martí B, Fernández-González E, Callejón-Ferre AJ, Cremades JE, 2012. Mechanized methods for harvesting residual biomass from mediterranean fruit tree cultivations. Sci Agric 69 (3): 180-188. https://doi.org/10.1590/S0103-90162012000300002

Witney B, 1996. Choosing and using farm machines. Land Technology Ltd. Edinburgh, Scotland, UK. 411 pp.

Yılmaz E, Çanakcı M, Topakcı M, Sönmez S, Agsaran B, Alagöz Z, 2017. The effects of application of vine pruning residue on soil properties and productivity under mediterranean climate conditions in Turkey. Fresenius Environ Bull 26: 5447-5457.