

The effect of different blades on the performance values of a pruning chopper used to improve soil properties

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Abstract

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Chopping is a critical process in recycling of the pruning residues at different forms. Choosing the right blades in machines used for this purpose will positively contribute to obtaining suitable particles and reducing the operation costs. The effects of the three different blade types on the performance values of a on the go machine, which is used in the orchards among intra-rows to chop the pruning residues were investigated in this study. The hammer, universal and Y type blades were used in trials for chopping the pruning residues of the pomegranate and orange. In this study, power and energy requirements and average geometric diameters of the chopped residues were determined. Based on the research results, the effect of the blade types used on power consumption of the machine and the particle size was found statistically significant. The maximum power consumption and the smallest particles were identified in the hammer blade for both pruning residues. These values were 22.28 kW – 11.63 mm for pomegranate and 19.29 kW 13.03 mm for orange, respectively. The lowest values, however, were determined in the Y type blade as these values were 13.44 kW – 14.15 mm for pomegranate and 10.44 kW – 17.11 mm for orange. The values obtained from all applications for energy requirement were calculated as 4.24 – 7.07 kWh t⁻¹ for pomegranate and 4.64 – 8.57 kWh t⁻¹ for orange.

Keywords: Pruning residue; chopping; power; energy; blades; particle size

Introduction

Plant residues showing different characteristics according to production branches are generated in agricultural production. One of the areas that have an important plant residual potential is orchards. Every year, significant amounts of residues in woody structure are produced after the pruning process. Pruning residues are specific materials that positively contribute to both environment and economy when utilized.

Therefore, interest in pruning residues has been increasing in recent years in terms of conversion of energy, environment, cultivation and economy (Fedrizzi et al., 2012).

Traditionally, pruning residues have been removed from orchards and burned, or they have been chopped by different machines in order to utilize them appropriately to fit the purpose. The immediate burning process eliminates the possibility of reusing of these residual materials; moreover, it causes environmental problems (Goncalves et al., 2011;

Spinelli et al., 2014). Hence, pruning residues produced in orchards have been tried to be utilized in different forms. After the chopping process, these residual materials can directly be mixed to the soil for increasing the organic matter ratio and protecting it from erosion. (Holtz et al., 2005; Çanakçı et al., 2010; Calatrava & Franco, 2011; Jimenez et al., 2013; Manzanares et al., 2017), or they can be used as compost (Çıtak et al., 2006), mulch (Spinelli et al., 2010), biomass (Şeflek et al., 2006), raw materials for power and industrial plants (Ntalos and Grigoriou, 2002; Korucu and Mengeloğlu, 2007; Yeniocak, 2008; Spinelli et al., 2010; Velazquez-Marti et al., 2011; Fedrizzi et al., 2012; Fernandez-Sarria et al., 2019) after having been chopped and subjected to different processes. The usual regional and enterprise practices and technological levels are also important for the application process of these methods. For instance, the on-site processing and mixing the soil with the pruning residues can be accomplished by a chopping machine. However, a chain of operations with more than one machine and logistics issues etc. also come to the forefront in order to utilize them as biomass, or industrial raw materials (Çanakçı, 2014). These applications involve costly infrastructures and systems. In countries such as Turkey, where utilization of the residues has recently been initiated, chopping the pruning residues on-site and mixing them directly with soil is more prominent application. For this application, mostly the chopping machines, which get their power from power take-off (PTO) shaft of the tractor, are used. Chopping of residues by a machine in orchards and leaving them on the soil surface, consequently, mixing the residues with soil by the ground processing machines contribute to the improvement of soil properties and allow these residues to be utilized in a very short period. With this method, which can also be defined as on-site utilization, plant residues are mixed with soil to enrich the organic matter content of the soil. Repullo et al. (2012) stated that mixing of organic matter with soil is a widely used method for sustainable agriculture.

Chopping is one of the critical processes with whatsoever method the pruning residues are utilized. Use of proper machines in chopping process is important in terms of shrinking the residues at desired particle sizes and minimizing the costs. Thus, selection of proper chopping machines and shredder blades are both technically and economically important.

The selection, operation and renewal of mechanization tools used for chopping process are considered within the scope of mechanization management (Witney, 1996). In addition, the obtained power values are used to determine the tractor overloading ratios and fuel consumption for operations. The unsuitable tools for enterprises reduce the capac-

ity and cause damages. Therefore, proper data should be used in order to be able to create applicable models (Rotz and Muhtar, 1992).

There have been several studies about chopping of the pruning residues in the literature. Çanakçı et al. (2010) determined working parameters for a pruning residue shredder. Recchia et al. (2009) tested a new shredding machine with packaging unit for recycling pruning residuals. Similarly, Spinelli et al. (2010) studied on the harvesting machines had baling and storage unit. Savoie and Gagnon (2011) were done some precise some measurements to improve the design and adjustment of the chopping operation in the laboratory conditions. Fedrizzi et al. (2012) conducted on experimental test for a prototype machine for harvesting and chipping of pruning residues. Velazquez-Marti et al. (2012) evaluated the harvesting operations for Mediterranean orchards. Adamchuk et al. (2016) designed and tested a new shredder for grape vine and fruit tree pruning. The number of studies experimented the effect of different blade types on machine performance is limited. Dereli (2009) used different machines and three types of blades only on the vineyard pruning residues in his study. In practice, however, use of machines in many products (universal) has been reported; and different type blades can be installed into these machines. Currently, there is a restricted knowledge in the literature about the blade selection for chopping of pruning residues.

The aim of this study, therefore, is to determine the effects of different blade types on the performance values of the machine that is utilized on-site on the orchard pruning residues. In the current study, two types of plant materials (pruning residues of pomegranate and orange) and three blade types were used in order to evaluate different conditions.

Material and Methods

A pruning residue chopping machine driven by the PTO of tractor shaft was used. The working width of the machine was 1700 mm and it contained 18 loosely connected blades with a rotational speed of 1827 min⁻¹. A tractor (NH TD75D) with a 55 kW engine was used as a power source in the experiments. The machine chopped the swath – type – aligned pruning residues while moving through the intra-rows in the orchards and left the chopped residues on the soil surface. The machine contained pickup, chopping and sieving mechanisms. The pictures of the chopping machine are given in Figure 1.

Three different blade types designated as the hammer, universal (triple) and Y type (dual) were used. In order to use them in chopping of pruning residues, their production



Fig. 1. Pruning Chopper

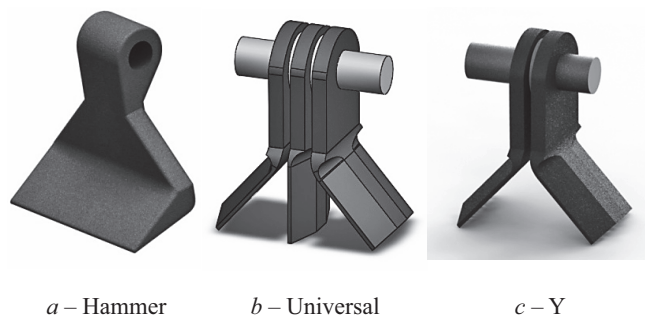


Fig. 2. Types of the blades

and selling in the current market conditions were taken into account while choosing the blade types. The pictures of the blade types used in the study are given in Figure 2.

The first blade type is called as hammer blade and is fixed to the rotor by a loose connection.

The material is chopped by a concave shaped blade in the chopping unit. The weight of each hammer blade is 1240 g. In the second blade type; however, there are three blades in a group. This type also known as the universal blade has two L shaped blades oppositely fixed to each other and one straight blade in the middle. The total weight of these blades is 1730 g. The third blade also called Y type contained two L shaped blades oppositely fixed to each other and the total weight of the two blades is 1190 g.

The experiments were carried out with the pomegranate and the orange pruning residues. The experiments on the orange pruning residues were carried out in an orchard of Fruit Farming Department of the Western Mediterranean Agricultural Research Institute, which is affiliated to the Ministry of Food, Ag-

riculture and Livestock (MFAL); whereas the experiments on the pomegranate pruning residues in a private orchard (Antalya Province, Turkey). Some characteristics of the experiment areas and the pruned materials are given in Table 1.

Table 1. Some characteristics of the experiment areas and the pruned materials

Characteristics	Pomegranate	Orange
Orchard establishment year	1998	1991
Inter-row distance, m	4	6
Intra-row distance, m	3	6
Average material thickness, mm	23.4±0.6	28.4±1.6
Slope, %	1	1
Material (residue) shape	Knotty	Knotty
Average swath width, m	1.63±0.05	1.52±0.03
Average swath height, m	0.48±0.04	0.60±0.05
Average material moisture, %	36.27±0.93	32.67±1.49

Before chopping process, the pruned residues were collected within the intra-rows and piled up in swath shape. In the study, where the randomized blocks experimental design with three replications was carried out, the swath length was taken as 25 m. This length in measuring system was a sufficient distance to obtain an average of 30 – 50 data (Işık, 1988) for each experiment. A single step (gear) and a suitable feeding rate (1.4 km h⁻¹) were operated in the experiment conditions.

The particle sizes of the obtained pruning residues and the operating parameters (feed rate, area and material capacities, and power and energy requirements) were taken into account as the main performance values while studying on the pruning residues.

In the study, a measuring system was used to determine the torque and the power of the PTO values. Signals received from the torque meter (Datum Electronic Series 420) were transmitted into the computer through an interface unit on the device in the measuring system. The torque meter with a capacity of 1800 Nm was directly connectible to the PTO output without requiring any additional parts. The torque meter was able to receive nine data per second at the PTO speed of 540 min⁻¹.

The total energy requirement per unit area was calculated as the ratio of the required tractor PTO power (kW) to the effective working capacity of the agricultural machine (ha h⁻¹) or material capacity (t h⁻¹) at the time of the performance of an agricultural operation.

In order to determine the sizes of the chopped particles, samples were taken from three different locations for each post – experimental material. To do that, an iron frame in a dimension of 1×1 m was placed in the swaths on the ground, and the whole chopped material remained in the iron frame was collected (Figure 3).



Fig. 3. Iron frame (1×1 m) and chopped materials

Then, the chopped material dimensions (length, width, and thickness) of the samples were measured. Since the dimension of the chopped material in three axes varied greatly from each other, it was not possible to define a material based on its single dimension. Hence, the average geometric diameters, which were common expression of the particle sizes based on three dimensions, were calculated. The five frequency intervals ($x < 4$, $4 \leq x < 7$, $7 \leq x < 10$, $10 \leq x < 13$ and $x \geq 13$ mm) were used to classify the average geometric diameters of the chopped materials in order to be able to obtain comparable results after the experiment. A digital caliper gage with 0.01 mm precision and a scale with 0.001 g accuracy were used to measure particle sizes. To determine the average geometric diameters of particles, the following equations were used (Şeflek et al., 2006; Çanakcı et al., 2010).

$$D_{geo} = \sqrt[3]{L.W.T}. \tag{1}$$

In the equation above; D_{geo} , stands for the average geometric diameter; U , the particle length; G , the particle width and; K , the particle thickness.

$$\delta_{ort} = \sum_{i=1}^n x_i f_i \tag{2}$$

In the equation above; however δ_{ort} stands for the average geometric diameter of the sample; the identified average geometric diameter in the i -th class; the % value of the material amount to the whole sample mass in the i -th class and; n , the number of the class.

To determine the effect of different blade types on power requirement and particle size, variance analysis was performed to the obtained data. Applications where the difference was found significant were subjected to the multiple comparison tests (Duncan).

Results and Discussion

Values related to the material density and machine capacity

The values of the machine capacity and the material density calculated from the pruning residues, which were obtained from two different orchards and three different blade types were given in Table 2.

As shown in Table 2, the density values of the material in a swath unit were identified as 2.65 kg m⁻¹ for the pomegranate and 1.89 kg m⁻¹ for the orange. Taking these values into consideration along with the intrarow space, the material mass values in a production area unit was calculated as 6.63 t ha⁻¹ for the pomegranate and 3.15 t ha⁻¹ for the orange.

Depending on the feeding rate, time utilization coefficient and inter-row distance; the field capacity values were identified as 0.476 ha h⁻¹ for the pomegranate residues and 0.714 ha h⁻¹ for the orange residues. The time utilization coefficient and forward speed were determined as 0.85 and 1.4 km h⁻¹ for the machine, respectively. These values showed similarity to studies related to chopping of pruning residues (Dereli, 2009; Reccia et al., 2009; Çanakcı et al., 2010). Since the speed rates for three blade types were the same, different blade types did not have any effect on the field capacity value. The distance values (4 m for the pomegranate and 6 m for the orange), which were considered as the working width of the machine, in different row spacing of orchards caused the field capacities to differ depending on the products. Since the machine worked at the same speed for both orchard residual materials, the inter-row distances had direct effect on the field capacity. Therefore, after such pruning processes, piling up of the chopped residues in one

Table 2. The experimental values obtained from the machine capacity and material density

Material	Swath Density kg m ⁻¹ *	Material Amount t ha ⁻¹ *	Area Capacity ha h ⁻¹	Feeding Density kg s ⁻¹ *	Material Capacity t h ⁻¹ *
Pomegranate	2.65±0.1	6.63	0.476	1.13	3.15
Orange	1.89±0.1	3.15	0.714	0.76	2.25

* represents the values obtained with 36.3% moisture (wb) for the pomegranate residues and 32.7% moisture for the orange residues.

for more inter-rows are recommended instead of each row spacing, if the density of the material is relevant.

Depending on the density of residual material in swaths and the field capacity values, the residual material capacity of the machine for pomegranate and the orange was calculated as 3.15 t h^{-1} and 2.25 t h^{-1} , respectively. Hence, it can be mentioned that the lower inter-row and intrarow distances in the pomegranate increased the amount of material per unit area. The field capacity and the amount of material per unit area influenced the amount of material chopped at a certain time unit.

Power and the Energy Values

During the experiment, the power values defined for the three different blade types, the hammer, universal and Y type (dual), are shown in Table 3. The energy requirement values for per unit mass of material (t) and per unit area (ha) are also given in Figures 4 and 5.

Table 3. Findings related to the power values

Material	Blade Type	PTO Power, kW	
Pomegranate	Hammer	22.28±0.78	a
	Universal	14.40±1.09	b
	Y	13.34±1.29	b
P		0.002	
Orange	Hammer	19.29±1.54	a
	Universal	11.26±0.86	b
	Y	10.44±0.74	b
P		0.002	

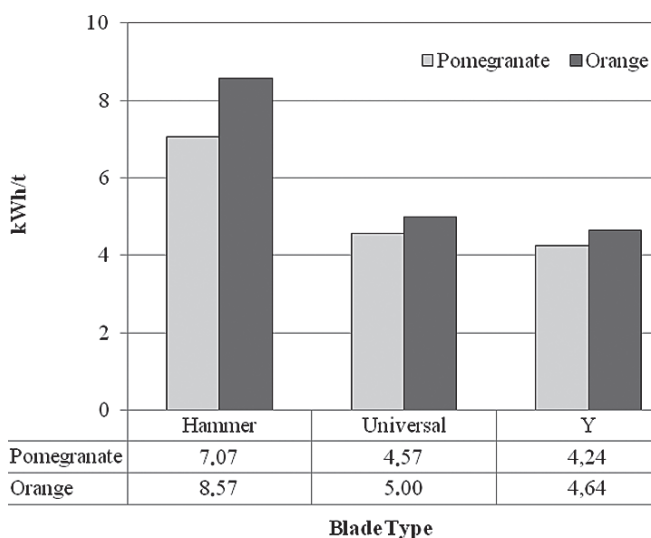


Fig. 4. Energy requirement values per unit of material mass

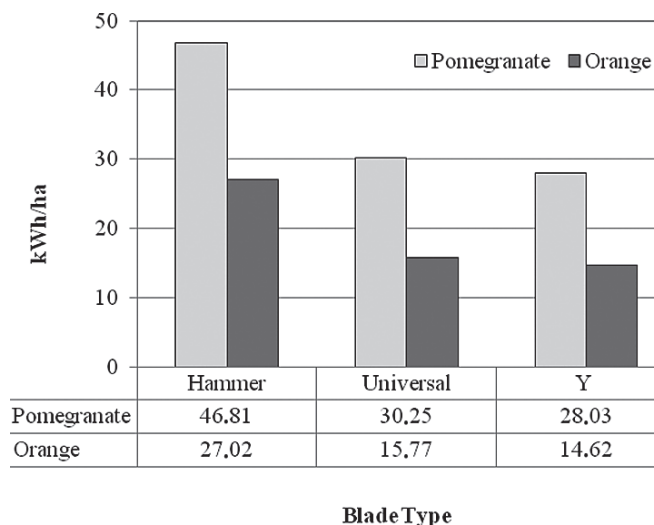


Fig. 5. Energy requirement values per unit area

According to the results of individual variance analysis performed for each blade type, the effect of different blade types on power consumption during the chopping of both pomegranate and orange pruning residues was found statistically significant ($P>0.01$). Based on the Duncan's multiple comparison tests to determine the difference between blade types; while the hammer blade had the highest power requirement, the universal and Y type blades required less power and were clustered in the same group (Table 3). The lowest power consumption value; however, was identified for the Y type blade in both plant residues as 13.44 kW for the pomegranate and 10.44 kW for the orange. These values were about 8% higher for the universal blade both for pomegranate and orange. The highest power consumptions were determined for hammer blade type as 22.28 kW for the pomegranate and 19.29 kW for the orange. These values were about 55% and 70% higher compared to the universal blade both for the pomegranate and the orange, respectively.

It was noteworthy that there was a high increase in the power requirement when working with the hammer blade type. The other two blade types performed in a style of crushing the material. However, the hammer blade chopped the material not only by crushing process, but also mixing and scrubbing it since the blade had large surface. Hence, this feature in the hammer blades was thought to increase power requirement. In addition, it could be said that when the chopped materials were analyzed; it is the opinion by the fact that the particles with hammer blades had rougher surfaces than the other blade types.

In a study conducted by Dereli (1999), the power consumptions in different machines were identified between 3.0

– 4.5 kW (at an approximate speed values and at lower densities) in the chopping process of orchard pruning residues. These values, however, were very low compared to those obtained in our study. It could be alleged that the difference in power consumption was arisen from different structural features of the machines, and varying materials and their densities. It is noteworthy that there were only the chopping units in three different machines used in the study conducted by Dereli (1999); however, no pickup unit and screening systems were available in the mentioned machines.

The energy requirement values per chopped material mass showed downward tendency between the hammer and Y type blades for both pruning residues (Figure 4). In working conditions, these energy values for the pomegranate residues were identified as 7.07, 4.57 and 4.24 kWh t⁻¹ for hammer, universal and the Y type blades, respectively. However, these values were 8.57, 5.00 and 4.64 kWh t⁻¹ for the orange residues, respectively. Taking the power and the area capacity values into account, the energy requirement values per unit area also showed similar variations. The hammer blade was the most energy requiring blade type in both pruning residues. The fact that the hammer blade type requires more energy similar to the power requirement should be taken into account in terms of machine administration and costs.

Particle Sizes

The pruning residues were chopped and left directly on the soil surface. Having the smaller sized particles in such applications accelerates the decomposition process and gain of these particles by soil. The values for the measured particle sizes are given in Table 4.

The average geometric particle diameter of the pomegranate pruning residues for the hammer blade, which required the highest power, was measured as 11.63 mm. This

value was 13.03 mm for the orange pruning residues. The largest particles, however, were identified in use of the Y type blades as 14.15 mm and 17.11 mm for the pomegranate and the orange, respectively. According to the variance analysis results, the effect of blade type on particle size was found statistically significant for both the pomegranate and orange pruning residues ($P > 0.01$). Also, according to the results of multiple comparison tests, the values of hammer type blades for the two different pruning residues was placed in separate groups. When considered with the values of power and energy, it is expected that the smallest particles would be obtained with the hammer blade and the largest particles with the Y type blades.

Based on the findings, it is considered necessary to emphasize the following issues.

Although there was no statistical difference between the universal blade and the Y type blade in terms of power consumption, it is important to note that the particle sizes obtained with the universal blade were smaller than the Y type blade.

Although the smallest particles were obtained with the hammer blade, it could be argued that this blade type chopped less than expected compared to the universal blade when their power values were compared. There is about 8% difference between both the power values and the particle sizes of the universal and the Y type blades in both pruning residues (Table 3 and Table 4). However, in comparison to the universal blade, even though there was about 54% excess of the power requirement for the hammer blade in pomegranate pruning residues, the shrinkage in the particle sizes remained at about 11%. Similarly, in the orange pruning residues, although the hammer blades consumed about 71% more power, the reduction in particle sizes was only about 17%. As also mentioned above in the power consumption section, the crushing process of pruning residues with the hammer blades occurred with the scrubbing effect in a narrow span between wide surfaces of the blades and the sieves. This feature is also thought to have increased the power consumption proportionately. That the particles in similar sizes obtained with hammer blades seemed to be more damaged compared to others can be argued to be an indicator of this process.

Conclusion

In this study, effects of different blade types on the performance of a pruning residue chopping machine driven by the PTO were investigated. Three different blades, namely the hammer, universal and Y type, were used in chopping process of the pomegranate and the orange pruning

Table 4. Values of average geometric diameters of the particles

Material	Blade Type	Average Geometric Diameter, mm	
Pomegranate	Hammer	11.63±0.27	a
	Universal	13.03±0.16	b
	Y	14.15±0.39	c
P		0.002	
Orange	Hammer	13.03±0.29	a
	Universal	15.66±0.32	b
	Y	17.11±0.56	c
P		0.001	

residues. According to the experiment results, effect of the blade types on the power consumption was found significant. The highest power requirement was determined in the hammer type blade to be 22.28 kW for the pomegranate and 19.29 kW for the orange. The lowest power requirement, however, was determined in the Y type blade to be 13.34 kW and 10.44 kW for the pomegranate and the orange, respectively. Depending on the power and capacity values, the unit energy values was calculated. Based on these values, the maximum energy requirement in the research conditions was determined for the hammer blade type. Regarding evaluation of the particle sizes, the effect of different blade types on particle sizes was found significant. The smallest particle sizes were measured as 11.63 mm for the pomegranate and 13.03 mm for orange pruning residues with the use of hammer blade. Although more power is consumed, smaller particle sizes are expected to be obtained in the use of hammer blade. However, when the hammer blade is compared with the universal blade, it is observed that it chopped less compared to more power consumption.

Based on the results, it is recommended to choose the universal blade type when energy economy and cost considerations become prominent, but to choose the hammer blade when smaller particle sizes become very important in the process of chopping of the pruning residues.

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