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DEVELOPMENT OF A MACHINE CHOPPING THE ORCHARD TREE REMNANTS, AS A SOLUTION FOR SUSTAINING CIRCULAR ECONOMY AND ENVIRONMENTAL PROTECTION IN HORTICULTURE

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Abstract

The experiments were conducted at Al-Gharbawi Farm in Delingat Center, Beheira Governorate, during 2022 agricultural season. This study aims to develop and evaluate an orchard tree residue shredder to be suitable for shredding large-diameter branches and scattering them between tree rows by doubling the number of knives on the drum shredder, increasing the thickness of the shredder diameter, and adjusting the size of the chairs and ball bearings of the drum shredder. The study was conducted at three forward speeds (1.8 - 3.2 - 4.6 km/h), three levels of moisture content (20 - 30 - 40%), number of knives (16 - 32), and four rotational speeds of the drum shredder (2,000 - 2,200 - 2,400 - 2,600 rpm). The evaluation was carried out in terms of shredder performance, machine productivity (tons/hour), shredding efficiency (%), cutting length ratios (%), machine energy requirements (kW.h/ton), and operating cost (pounds/ton). The results can be summarized as follows: Increasing the cutter head speed from 2,000 to 2,600 rpm increases the cutting length ratio ≤ 3 cm from (55.5 to 61.5%), cutting efficiency from (90.9 to 95.5%), useful power from (25.59 to 22.18 kW) and energy from (9.66 to 9.45 kWh/ton) with the machine before modification at 40.0% moisture content (g weight) and number of cutting knives (original knives). The cutting length ratio ≤ 2 cm increased from (69.5 to 75.3%), cutting efficiency ratio from (87.1 to 95.5%), useful power from (28.12 to 27.18 kW) and energy from (32.7 to 9.43 kWh/ton) with the machine after modification at 40.0% moisture content (g weight) and number of cutting knives (modified knives).

Key words: *a chopping machine, trees remnants in orchards, circular economy*

INTRODUCTION

In Egypt, the agricultural residues, mainly orchard trimming residues, pose a significant environmental and agricultural challenge in the country to reduce environmental pollution and provide organic fertilizers to the soil to improve its physical and chemical properties, reduce the growth of weeds among orchard trees, and increase its ability to keep water for the longest possible period, especially with the limited water resources.

Chopping agricultural residues to feed the remnants is becoming increasingly recognized as a sustainable trend [2], [7], which could contribute to the circular economy and environment protection [5, 6].

Mechanical treatment is the primary approach to utilizing raw materials in various processes. Using pruning residues is beneficial for both the environment and the economy. Horticultural crop production holds a significant position within the various branches of agricultural cultivation.

In contrast to other crops, horticultural trees are perennial plants that require annual or periodic pruning to enhance their production's quality and quantity.

Hence, there has been a growing interest in using pruning residues for energy conversion and environmental concerns, agriculture, and economics [9].

Historically, orchard pruning residues were disposed of by burning or utilizing various machinery.

The immediate combustion process prevents the potential for reutilizing these residual materials and engenders ecological concerns [16].

Consequently, the act of chopping residues not only increases field coverage but also facilitates the recycling of pruning residues in olive orchards. In order to achieve this aim, the pruning residues are systematically aligned in a straight line, consolidated at the central portion of the rows, and then mechanically chopped by a grinder linked to a tractor [18].

Therefore, it is essential to ensure the retention of residues in the soil for the second year. Adequate maintenance and distribution of sufficient residues are necessary to ensure soil coverage, a crucial element in erosion reduction and water balance improvement [14].

Alternatively, the waste from pruning is mulched, left on the ground, or integrated into the soil [13].

Therefore, attempts have been made to utilize pruning residues generated in orchards in various ways.

Once the materials are chopped, they can be mixed directly into the soil to enhance the organic matter ratio and safeguard it against erosion [15].

One commonly employed approach to preserving organic matter in the soil and mitigating rain-induced erosion is using inert coverage, such as recycled crop residues or deceased cover crops [11], after having been chopped and subjected to different processes. For example, a chopping machine can perform on-site processing and effectively mix the soil with the pruning residues. The forefront also highlights operations involving multiple machines and logistics challenges in utilizing them as biomass or industrial raw materials [4].

Implementing these applications causes expensive infrastructures and systems. In nations like Turkey, where the utilization of residues has recently begun, on-site pruning residue chopping and direct integration with soil is a prevailing approach. Chopping machines, primarily powered by the tractor's power take-off (PTO) shaft, are predominantly utilized for this specific purpose.

Machine-chopping residues in orchards and leaving them on the soil surface, then mixing them with soil using ground processing machines, significantly enhances soil properties and facilitates their rapid utilization.

By employing this approach, commonly referred to as on-site utilization, plant residues are combined with soil to enhance the organic matter composition of the soil.

Chopping is one of the critical processes; pruning residues are used in any method. Employing appropriate machinery during the chopping procedure is crucial for reducing residues to the desired particle sizes and minimizing expenses.

Therefore, appropriate cutting machinery and shredder blades hold significant technical and economic importance.

Numerous studies have been conducted regarding the fragmentation of pruning residues in the existing literature.

New pruning equipment has been developed and evaluated for pruning grapevines, as well as fruit trees.

There is a paucity of studies that have explored the effect of different blade types on machine performance [1].

The importance of agricultural crop residues, especially in horticulture, has been highlighted as a pressing environmental and agricultural concern in Egypt.

Therefore, the aim of this study is to ascertain the effect of different blade types on the performance metrics of on-site machines for managing orchard pruning residues. Improper disposal of wood waste has a detrimental impact on both aquatic and terrestrial ecosystems [10].

An analysis of both the adoption and spread of the practice of using chopped pruning residues as mulch in olive groves in the province of Granada, southern Spain [3].

Burning waste from orchard trees releases greenhouse gases into the atmosphere, a range of human health problems. By utilizing technology to divide the cut vine stems and branches into pieces less than 10 cm long and then incorporating them into the soil between rows of plants annually, it becomes possible to reuse the cut pruning material as organic fertilizer.

This approach helps reduce the above-mentioned losses and contributes to environmental conservation.

The objective of the research is the development and evaluation of a tree residue chopper suitable for cutting large diameter branches and distributing them between tree rows.

MATERIALS AND METHODS

The locally developed cutting machine was modified in a private workshop in Al-Shaarawi Village, Al-Delangat Center, Beheira Governorate.

The development of a local cutting machine has a working width of 1,600 mm and has 32 loosely connected blades to chop orchard tree pruning waste suitable for cutting branches of large diameters and scattering them between the rows of trees.

The pruning residue-cutting machine was operated via a PTO pole, and it is suspended behind the tractor between the rows of orchard trees, where it cuts the pruning residue as it moves between the rows of orchard trees and leaves the cut remains on the surface of the soil.

The tractor was used to operate the machine is a Belarusian four-wheel-drive machine with a power of 92 hp.

- The field experiment was conducted on an area of 5 feddans to evaluate the operating parameters that affect the energy and energy requirements for cutting fruit tree waste, and to achieve the aims of this study, the cutting machine was used according to the following variables.

During the present study, machine chopping was evaluated using the new machine chopping in comparison with the original machine chopping.

The following treatments were tested:

(1)The humidity content of residues (20, 30 and 40%) (w.b.).

(2)Three forward speeds of tractor (1.8, 3.2, and 4.6 km/h).

(3)Four speeds of the drum (2,000, 2,200, 2,400, and 2,600 rpm), (41.8, 46, 50.6, 54.3 m/s), respectively. Where: linear speed (v) $=w.r= 2\pi N/60$.

The experiment was conducted and statistically designed as a factorial complete randomized block design with three replications.

Machine chopping

The components include the main frame, cutting drum, cutting knives, and gearbox. The chopping machine's length, width, and height measured 160 cm, 56 cm, and 90 cm, respectively. The cutting drum is fabricated using a steel shaft measuring 50 mm in diameter and 1,400 mm in length. The cutting drum is supported on the frame by two bearings. The mechanism operates through the use of a pulley and belts that are connected to a gearbox.

Two iron flanges were welded on both sides of the cutting drum, with diameters and thicknesses of 25 cm and 12 mm, respectively. Knives of a particular type were employed in the present study to cut the orchard residues. These knives were equipped with 32 sharp edges. They are made from steel sheets. The dimensions of the knife drum length, was 120 cm width, 20 cm and the thickness were 16 mm as shown in Fig 1, 2, 3 and Table 1.

Table 1. The machine chopping specifications

Characteristics	Machine chopping before	Machine chopping after
Overall length, width, height (mm)	1600, 900, 600	1600, 900, 600
Thickness of the roller (mm)	8	16
The internal diameter (mm)	30	60
Diameter of chopper drum (mm)	200	200
Weight (kg)	280	350
Number of knives on cutter head	16	32

Source: Authors' determination.

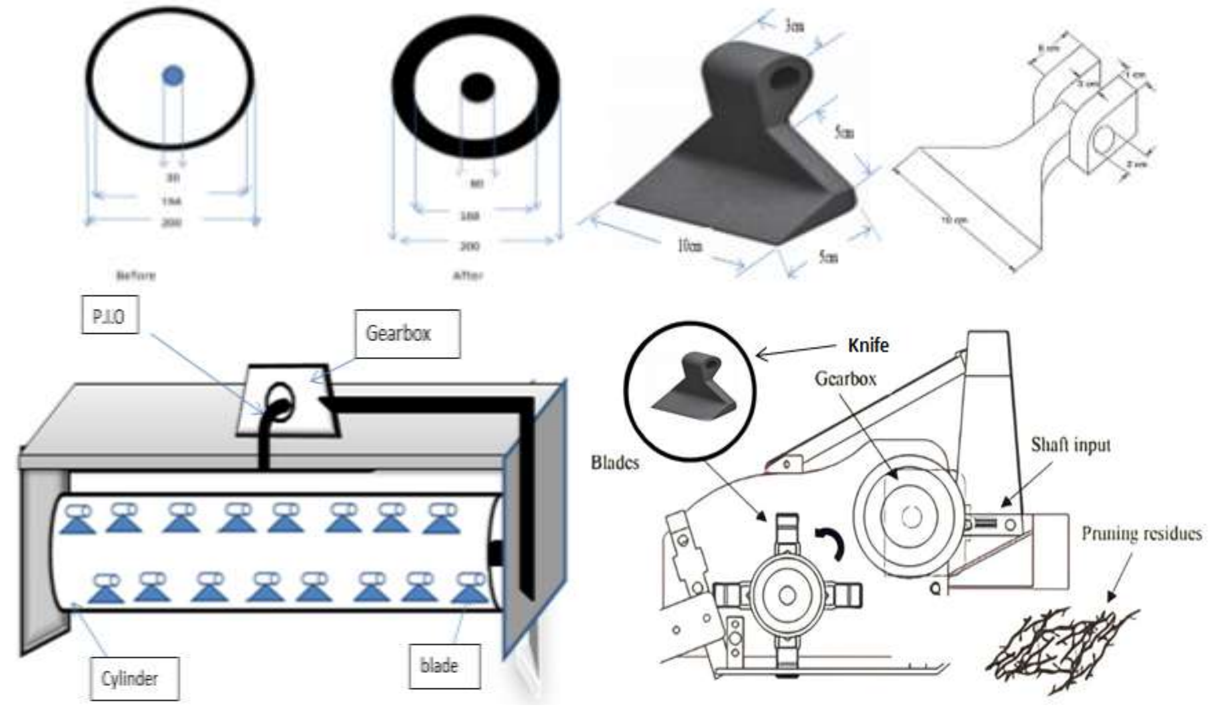
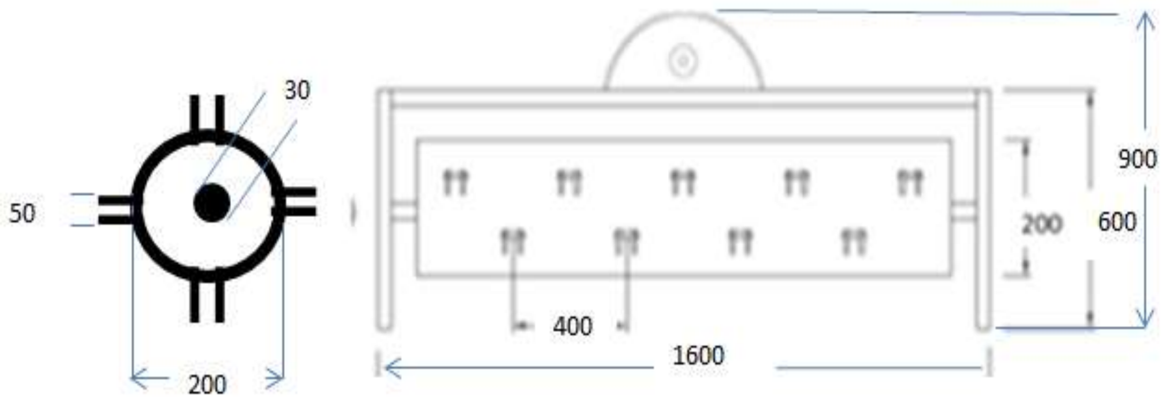
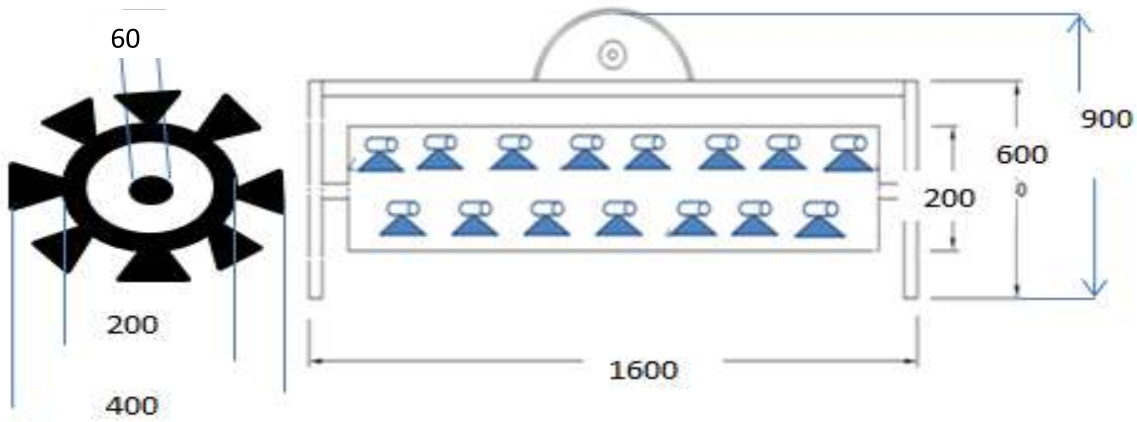


Fig. 1. Illustration of a machine for shredding orchard tree waste
Source: Authors' drawing .



Dimensions in mm, Scale: 1: 10

Fig. 2. Machine chopping before modification
Source: Authors' drawing.



Dimensions in mm, Scale: 1: 10

Fig. 3. Machine chopping after modification.
Source: Authors' drawing.

Measurements and determinations

-Cutting length percentage.

Theoretical and actual lengths of cut:

The theoretical lengths of cut L_{th} was calculated using equation (1), [17]

$$L_{th} = \frac{60000\ V_f}{N_k n_c} \quad \text{.......................................(1)}$$

where:

L_{th} = Length of cut, cm;

V_f = The velocity of feeding, m/s (feeding mechanism peripheral speed);

n_C = Rotational speed of Cutterhead, rpm, and

N_K = Knives number on the cutter head.

Following each chopping treatment, laboratory analysis involved random sampling of chopped material in 1 kg increments. The samples were subsequently separated into three categories (<30, 30-50, and ≥50 mm) using sieves to detect the actual average cutting length (Lac). The weight of each cutting length in the sample was measured and expressed as a percentage relative to the total weight of the sample.

- Chopping efficiency

Three samples each of 1 kg of cutting crop material were fed into the chopper for each treatment; after completing the chopping operation, the output materials were weighted, and the chopping efficiency was calculated according to equation (2):

$$\text{Chopping efficiency} = \frac{W_{output} - W_{uncut}}{W_{in}}\ \% \text{.. (2)}$$

where:

W_{out}: output mass, kg

W_{in}: input mass, kg

W_{uncut}: un-chopped mass after chopping process, kg.

Chopping efficiency was determined using equation (3) [8].

Chopping efficiency = 100 – un-chopped remnants .... (3)

-Machine productivity (L_{th})

The productivity of the machine was determined using equation (4).

Machine productivity

$$(L_{th}) = \frac{W}{t} \text{.......................................(4)}$$

where:

W = Weight at crop residues, ton;
t = machine operating time, h.

-Moisture contents:

The moisture contents of the plants were determined using the standard oven method. The samples underwent oven-drying at a temperature of 105°C for 24 hours. The determination of moisture percentages was conducted on a wet basis according to equation (5):

$$\text{Moisture content, \%} = \frac{(M_W - M_d)}{M_W} \times 100 \text{...(5)}$$

where: M_w is the sample's mass before cutting, kg

M_d is the mass of the cut sample, kg.

-Fuel consumption:

In order to calculate the fuel consumption during the harvesting operation, the quantity of fuel necessary to refill the Fuel tank after a working period was measured. A calibrated glass cylinder was utilized to determine the amount of fuel added. The calculation of fuel consumption was determined utilizing equation (6).

$$F_c = C_i - C_c \text{.....................................(6)}$$

where:

F_c is Fuel consumption, L/h.

C_i is Full tank capacity, L

C_c is the amount of remaining fuel in the tank after a specific period

-Power required:

The power requirement (B_p) was determined by applying equation 7 [12].

$$B_p = 3.163 \times F_c \text{ ....(7)}$$

where:

B_p = Power requirement, kW

F_c = Fuel consumption, L/h.

-Specific consumed energy:

The power requirement (kW) was assessed using a wattmeter, and the energy requirements (kW.h/ton) can be calculated by dividing the required power by the productivity of the machine:

The specific consumed energy was calculated from equation (8).

Specific consumed energy kW.h/ton =

$$\frac{\text{Power requirement,kW}}{\text{machine productivity}} \text{.............................(8)}$$

RESULTS AND DISCUSSIONS

Cutting length categories:

Figure 4 presents the relationship between the cutting rotor speed, number of knives, moisture content of the pruning waste, and their effect on the cutting length categories. The results showed a positive correlation between the increase in cutting rotor speed, moisture content of the pruning residue (<3 cm and 3-5 cm), and the corresponding increase in cutting length categories. In comparison, the > 5 cm cutting length category decreased. The findings revealed that the increase in the number of knives recorded a high percentage of the category of less than 3 cm when cutting waste. The highest percentage for cutting pruning waste with lengths of less than 3 cm (63.5%) and the highest percentage for cutting pruning waste with lengths of 3-5 cm (34.5%). As well as the lowest percentage of category greater than 5 cm (2%) was obtained under the rotor speed of 2,600rpm and the moisture content of 40% and using the number of cutting knives of 32.

Productivity:

The results obtained and shown in Figure 5 show that increasing the cutting rotor's speed and increasing the pruning residue's moisture content leads to increased productivity when free knives are used, and their number increases from 16 to 32. The results showed that productivity was increased using knives 32. The results also showed that the highest productivity reached 2,755 tons/hour, recorded at a rotating speed of 2,600rpm and a moisture content of 40%, using 32 knives.

Cutting efficiency:

The data in Figure 6 show that the cutting efficiency increased as the cutting rotor speed increased and the moisture content of the pruning residue increased. Also, increasing the number of free knives to 32 records a high value in cutting efficiency compared to the number of knives 18. The results show that using 32 free knives recorded the highest cutting efficiency value of 94.9% at a rotor speed of 2,600 rpm and a moisture content of 40%. This is because pruning residues have high elasticity. More knives are needed, and the cutting area must be cross-sectional. This is available for free knives

Fuel consumption:

Figure 7 reveals a positive correlation between cutting drum speed, number of knives, and fuel consumption. The increased cutting drum speed led to a corresponding increase in fuel consumption. As an illustration, the fuel consumption rose from 8.1 l/h to 8.3 l/h when the cutting drum speed was increased from 2,000 rpm to 2,600 rpm. As the number of knives increases, fuel consumption decreases. This could be attributed to the need for a more comprehensive understanding of the material to reduce consumption, such as a decrease from 8.5 l/h to 8.3 l/h when the knife numbers are increased from 16 to 32 at a cutting drum speed of 2,600 rpm.

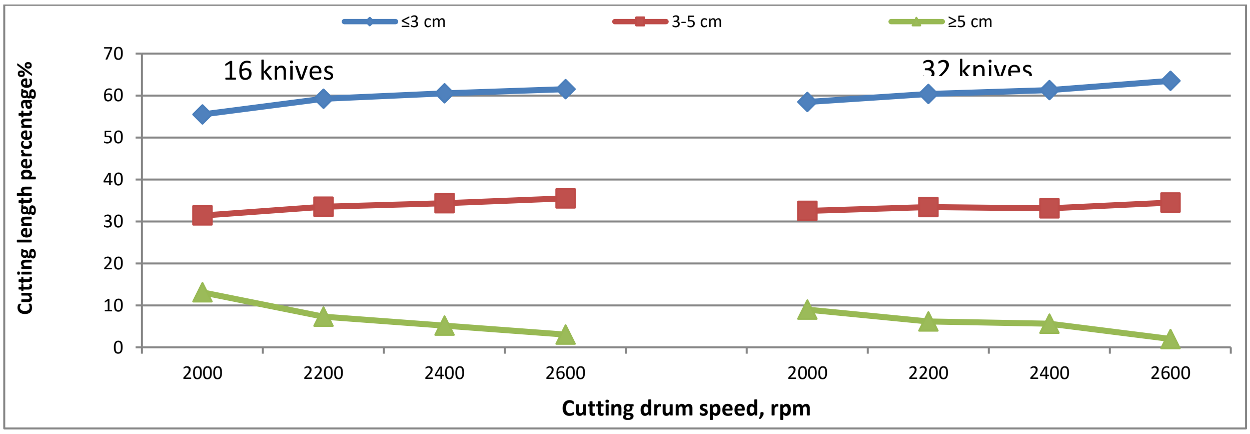


Fig. 4. Effect of chopping drum speed and knives number on cutting length
Source: Authors' determination.

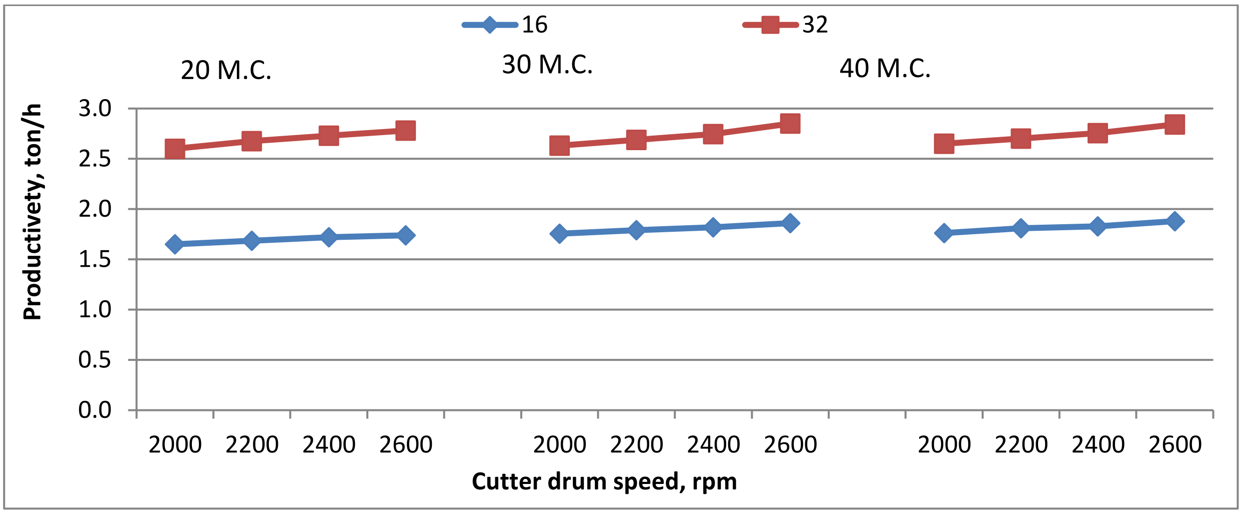


Fig. 5. Effect of chopping drum speed, moisture content, and knives number on machine production
Source: Authors' determination.

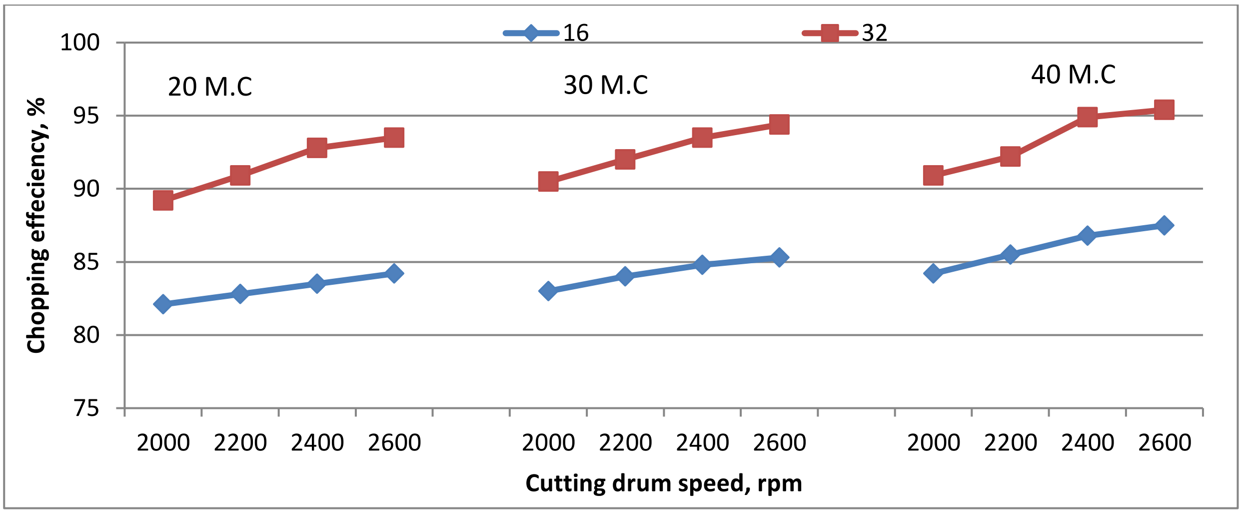


Fig. 6. Effect of chopping drum speed, moisture content, and knives number on chopping efficiency
Source: Authors' determination.

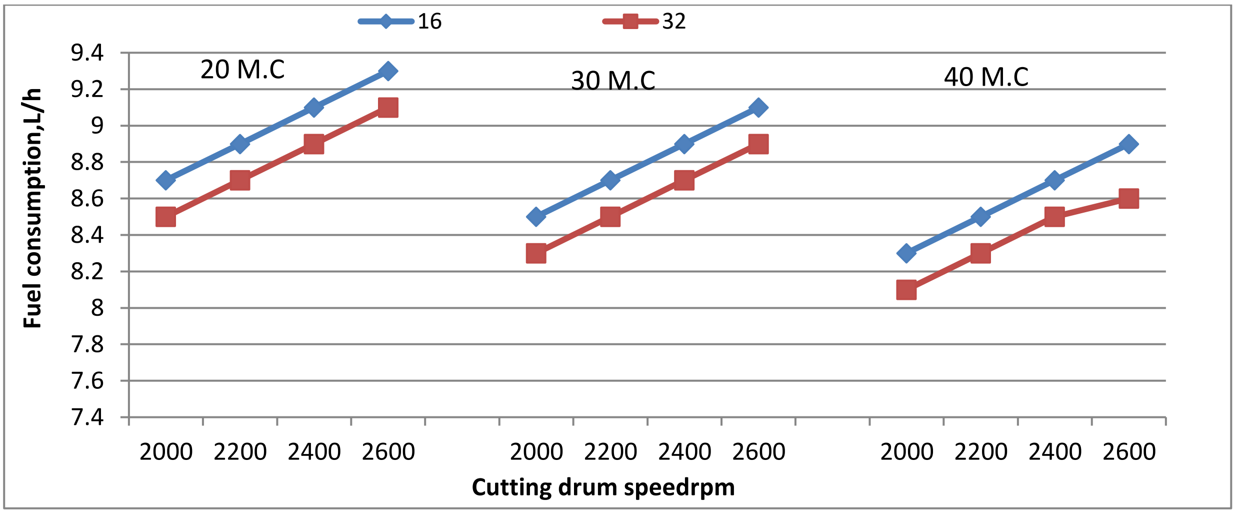


Fig. 7. Effect of chopping drum speed moisture content, and knives number on fuel consumption
Source: Authors' determination.

Energy requirements

Figure 8 illustrates a decrease in energy requirement as the cutting rotor speed and moisture content of the pruning residue increase while using 36 knives. The minimum energy requirement for cutting pruning residue was determined to be 25.04 kW.h/ton. The findings show that a cutting-knives speed of 2,600 rpm and tree branches moisture content of 40% resulted in a minimum specific energy of 9.43 kW.h/Mg. Conversely, a cutting-knives speed of 2,000 rpm and tree branches' moisture content of 40% yielded a maximum specific energy of 9.66 kW.h/ton.

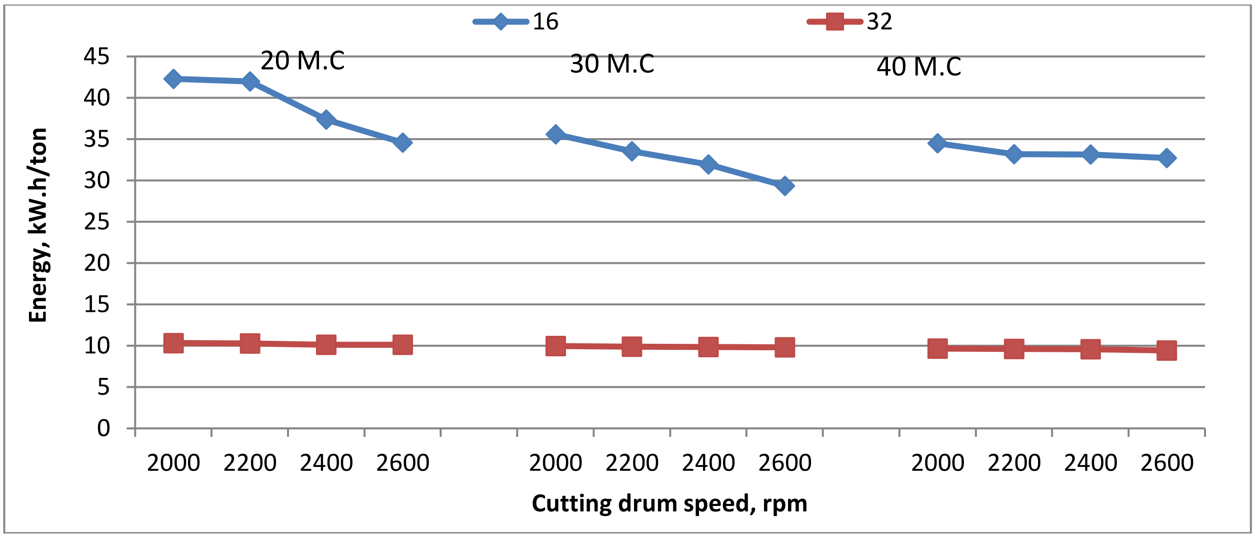


Fig. 8. Effect of chopping drum speed, moisture content, and knives number on energy requirement.
Source: Authors' determination.

CONCLUSIONS

The performance of the residue shredder was affected by many factors such as knife rotational speed, moisture content of the pruning residue, and the number of blades used. Modifying the thickness of the cylinder carrying the knives from 8 mm to 16 mm increases its durability to withstand chopping orchard tree branches up to 5 cm thick and protect them from damage because they operate at a speed of 2,600 rpm. The chairs carrying the cylinder were modified by increasing the inner diameter from 35 mm to 60 mm to withstand the weight of the cylinder and the load on the cylinder when cutting. The knife's weight was increased from 500 g to 1,240 g of 30Mn5 steel alloy. The number of knives was also increased from 16 to 32 knives. After modification of the machine, cutting length ratio ≤ 2 cm increased from 69.5% to 75.3%, cutting efficiency from 87.1% to 95.5%, useful power from 28.12 kW to 27.18 kW, and energy use from 32.7 to 9.43 kWh/ton at 40% moisture content with modified knives.

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