THE REQUIRED ENERGY FOR CUTTING OPERATION OF SOME FIELD CROP RESIDUES

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ABSTRACT

The performance of an experimental crop residues cutting machine has been investigated in this work in order to evaluate the energy requirements for cutting operation of three different crop residues (cotton stalks, corn stalks, and rice straw). The effect of cutting drum speed, knife edge angle and clearance distance on the machine productivity, fuel consumption, required power, specific consumed energy, cutting efficiency and the economical costs at optimum machine operation were, also, studied. The machine evaluated at five cutting drum speeds 1200, 1300, 1400, 1500 and 1600 rpm (8.29,8.98,9.68,10.37 and 11.06m/s); five knife edge angles (20°, 25°, 30°, 35° and 40°); and five clearance distance (1, 2, 3, 4 and 5mm). The results showed that the maximum cutting efficiency for cotton stalks (20.56% M_{cwb}), corn stalks (25.64% M_{cwb}), and rice straw (14.8% M_{cwb}) were 67.7%, 47.59,% and 62.75%, respectively, at 1600 rpm cutting drum speed, 20°knife edge angle, and 1mm clearance distance.

Keywords: Cutting machine; crop residues; energy requirements; cutting efficiency.

1. INTRODUCTION

Field crop residues are organic materials which are produced by products from harvesting and processing of agricultural crops. They include all agricultural wastes of common crops such as cotton, wheat, corn or maize and rice. Large quantities of crop residues are produced annually in Egypt. They reached about 18.7 million ton per year and the national income might be increased with 1.6 billion LE/year if we try to recycle it **(El-Berry *et. al.*, 2001 and Awady *et. al.* 2001, cited by El-Hanfy and Shalby, 2009).**

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The area of cotton crop cultivation produced about 9% of the total amount of the crop residues per year. The total cultivated area of rice is approximately 1.46 million feddan which is considered one of the most widely cultivated cereal crops in Egypt. It is produced about 3.28 million tons of rice straw per year according to the **Ministry of Agriculture and land Reclamation, 2006**. Consequently, the increase of field crop residues will cause a serious problem facing the agricultural producers because they are burnt or left to decompose, but most of these current practices are not working well because of wasting time, money, energy, and polluting the environment; However, there are many efficient and simplest methods of using the field crop residues, and all of these methods depend on the cutting process which may be chopping or shredding of the field crop residues for size reduction to be suitable for various uses such as food for farm animals, compost to substitute the chemical fertilizers and improve the agricultural soil, traditional source of domestic fuel in rural areas, and it can, also, be used in manufacturing. **Taiab and Imbabi (1995)** proved that the cutting energy and force requirements increased with increasing the stem diameter. **Habib *et. al.* (2002)** found that the predominant parameters affecting the cutting process performance of agricultural material were related to the cutting tool, machine specifications and plant material properties. **Suliman *et. al.* (2010)** studied some engineering factors concerning the performance of the affecting tool in crop residues shredder. Their results indicated that cutting drum speed, knife edge angle, and clearance distance are affected the cutting efficiency, fuel consumption and the shredder production. They, also, mentioned that the proper selection of new material leads to decrease the sharp edge angle of modified knives to 20° degree without deformation.

The present work aims to investigate and evaluate the performance of an experimental crop residues cutting machine that is owned by the Aried Land and Agricultural Research and services center, Faculty of Agricultural, Ain Shams University to determine the energy requirements for cutting operation of three different crop residues which are cotton stalks, corn stalks and rice straw. It also discusses:

1- The effect of cutting drum speed, knife edge angle and clearance distance on machine productivity, fuel consumption, required power, specific consumed energy and cutting efficiency.
2- The economical costs at optimum machine operation.

2. MATERIALS AND METHODS

The experiments of this work were conducted in Agric. Eng. Dept., Fac. of Agric., Ain Shams Univ. in 2012. The following material and methods were used:

3-1-Crop residues cutting machine:

An experimental cutting machine of crop residues was manufactured by Daeheuug machine ery Co., LTD, Seoul, Korea. It is illustrated schematically in Fig. (1) and photographed in Fig. (2). It is owned by the Arid Land and Agricultural Research and Services Center, Fac. of Agric., Ain Shams Univ. It consisted of the following main components:

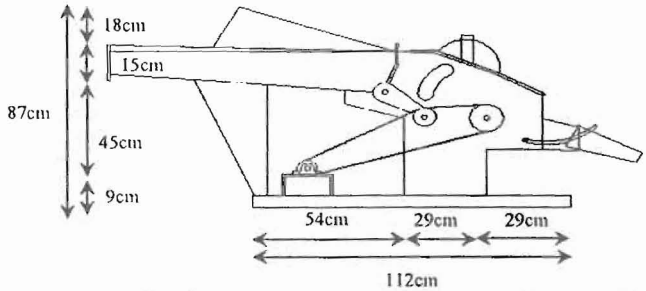

Fig. (1): Schematic diagram of crop residues cutting machine.

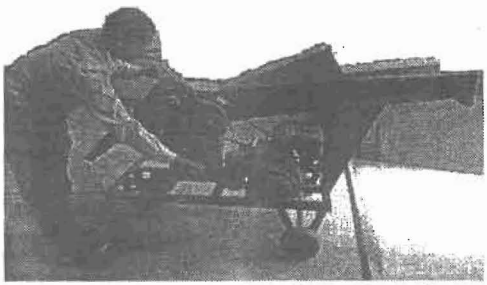

Fig. (2): Photograph of crop residues cutting machine.

3-1-a- Engine:

A single cylinder, four stroke, air cooled, spark-ignition engine DLS' 267 CC

Rated HP: 5/3600 rpm

Max. HP. 6/4000 rpm

3-1-b- A rotary cutter drum:

It has four knives rotating in vertical plane. The drum has 12 cm outer diameter, 6 cm inner diameter, and 17 cm length.

3-1-c- Knives

Four knives are distributed on the periphery surface of the cutter drum, they are made of steel. The knife dimensions are 17cm length, 4.5cm width and 6mm thickness. Five groups of knives were fabricated with different edge angles (20, 25, 30, 35 and 40°) to study the effect of the knife edge angle on the machine performance.

3-1-d- A stationary countershear

A stationary countershear (17 cm length, 10 cm width and 6 mm thickness) is fixed to the supporting machine frame. So, the crop material is sheared as the knife passes over the countershear.

3-1-e. Power transmission:

The power is transmitted from the engine to the rotary cutter drum by means of a set of pulleys and V-belts, as shown in fig. (1).

3-2- Moisture content of the crop residues:

The moisture content of the crop residues was determined using the standard oven methods. Samples of crop residues were weighted (using an electrical balance, 0.01 g accuracy) and dried in an oven at 103°C for 24h. The moisture content for each sample was calculated on wet basis using the following equation (**Henderson and Perry, 1981**):

$$M_{cwb} = \frac{M_b - M_a}{M_b} \times 100 \qquad \longrightarrow \qquad (1)$$

Where:

M_b and M_a are the masses of the sample (g) before and after drying, respectively.

M_{cwb} is the moisture contents (%) based on wet bases.

3-3- The machine productivity:

Three samples (about 3Kg each) were taken from each air-dried crop residues. Each sample was fed to the machine. The output of cutting material was collected and the corresponding time was recorded with the help of a digital stop watch of 0.1 second accuracy. Then the output material was weighted, and the average machine productivity was calculated as.

$$P_{rod} = \frac{machine\ output\ (g)}{Corres\ ponding\ time\ (s)} \times \frac{3600}{10^6} \longrightarrow \quad (2)$$

Where: P_{rod} is the machine productivity (ton/h)

3-4- Fuel consumption:

Fuel consumption per unit time was determined by measuring the volume of the consumed fuel during the experiment time. It was calculated as the following:

$$F_c = (V/t) \times 3.6 \longrightarrow \quad (4)$$

Where:

F_c = Fuel consumption rate, l/h; V = Volume of consumed fuel, cm^3 ; and t = Time of the experiment, S.

3-5- Power requirements:

Engine power that was required to drive the cutting machine of crop residues was estimated using the following formula (Embaby, 1985):

$$R.E.P. = (F_c \times \frac{1}{3600})\rho_f \times L.C.V \times 427 \times \eta_{th} \times \eta_m \times \frac{1}{75} \times \frac{1}{1.36} \longrightarrow \quad (5)$$

Where :

R.E.P = Power requirements from fuel consumption, Kw; F_c = Fuel consumption rate; L/h; ρ_f = Density of the fuel, Kg/L (assumed 0.85 Kg/L for gasoline; L.C.V.= Lower calorific value of fuel; Kcal/Kg (assumed 10000 $Kcal/Kg$ for gasoline); 427 = Thermo-Mechanical equivalent; Kg m/kcal); η_{th} = Thermal efficiency (assumed to be 35% for gasoline engine; and η_m = Mechanical efficiency (assumed to be 80%).

3-6- Specific consumed energy:

The specific consumed energy was calculated using the following equation:

$$S.C.E. = (R.E.P.)/P_{rod} \longrightarrow (6)$$

Where:

S.C.E. = Specific consumed energy; kWh/Ton
R.E.P = Required engine power; kW
P_{rod} = Machine productivity; Ton/h.

3-7- Cutting efficiency:

Cutting length of final machine output is a critical factor of cutting process for producing compost and forage. The suitable cutting length (L_c) should be in the range of $0<L_c < 50$mm **(Habib *et al.*, 2002),** and the cutting efficiency could be calculated as:

$$\delta_c = S_a/S_b \times 100 \longrightarrow (3)$$

Where :

S_b = Is the mass of the chopped material before segregation (g)
S_a = Is the mass of chopped material (after segregation) of cutting length, $O < L_c < 50$ mm (g).
δ_c = Is the cutting efficiency (%).

Therefore, a sample was taken from the final product and weighted, to find the mass of S_b, than it segregated using standard sieve (50 mm mesh) and the mass of S_a was determined. Finally, equation (3) was applied.

3-8- Cost estimation

The economical costs per hour of operation of the crop residues cutting machine was estimated using the following expression that was developed by **Awady (1978)** as:

$$T_C = [C/h] \times [1/L + i/2 + t + r] + [1.2 \times F_c \times f] + [m/144] \longrightarrow (7)$$

The following assumptions were used:

C = The initial price of the crop residues cutting machine = 4000 LE.
h = Work hours per year = 3000; l = Life expectancy = 15years;
i = Ratio of annual interest = 0.1; t = Ratio of annual taxes = 0.01; r = Ratio of annual repairs and maintenance = 0.035; F_c = Fuel consumption at the best machine cutting efficiency; L/h (measured); F = Fuel price; 1.1 LE/L; and m = Operator monthly salary = 900 LE.
The operator monthly average working hours = 144
T_c = Cost per hour of operation; LE/h

$$\text{Cost per ton} = \frac{T_c \left(\frac{LE}{h}\right)}{P_{rod}\left(\frac{Ton}{h}\right)} = \left(\frac{LE}{Ton}\right)$$

3. RESULTS AND DISCUSSION

Results presented in this section were obtained for three different types of crop residues (cotton stalks, corn stalks and rice straw). For each type, the cutting machine was tested to determine the machine productivity, fuel consumption, required power, specific consumed energy and cutting efficiency. The machine was evaluated at : a) five cutting drum speed (1200,1300,1400,1500 and 1600 rpm or 8.29, 8.98, 9.3.68, 10.37 and 11.06 m/s); b) five clearance distance (1,2,3,4 and 5mm); and c) five knife edge angle (20°, 25°, 30°, 35 and 40°).

3-1- Cotton Stalks

3-1-1- Machine Productivity:

Fig. (3) shows that machine productivity increased with increasing the cutting drum speed. It increased by an average 24.24% with increasing the cutting drum speed from 1200 to 1600rpm, at 20° knife edge angle, 1mm clearance distance, and 20.56% M_{cwb}. They, also, show that productivity decreased with an average 40.48% with increasing the knife edge angle from 20° to 40° at 1600rpm cutting drum speed and 1mm clearance distance. This may be due to difficulty of the penetration into the material with increasing the knife edge angle **(Suliman *et.al.*,2010).** It can be, also, noticed that there was slight increase of the machine productivity with increasing the clearance distance. It increased by an average 2.94% with increasing the clearance distance from1 to 5mm at 1600rpm cutting drum speed, 20° knife edge angle, and 20.56% M_{cwb}. Maximum and minimum rate of machine productivity at 20.56% M_{cwb} are given in Table (1).

Table (1): Max. and Min. rate of machine productivity, for cotton stalks.

Productivity (ton/h)	Engineering factors		
	Cutting drum speed (rpm)	Knife edge angle	Clearance distance (mm)
Max. = 0.0476	1600	20°	5
Min. = 0.0195	1200	40°	1

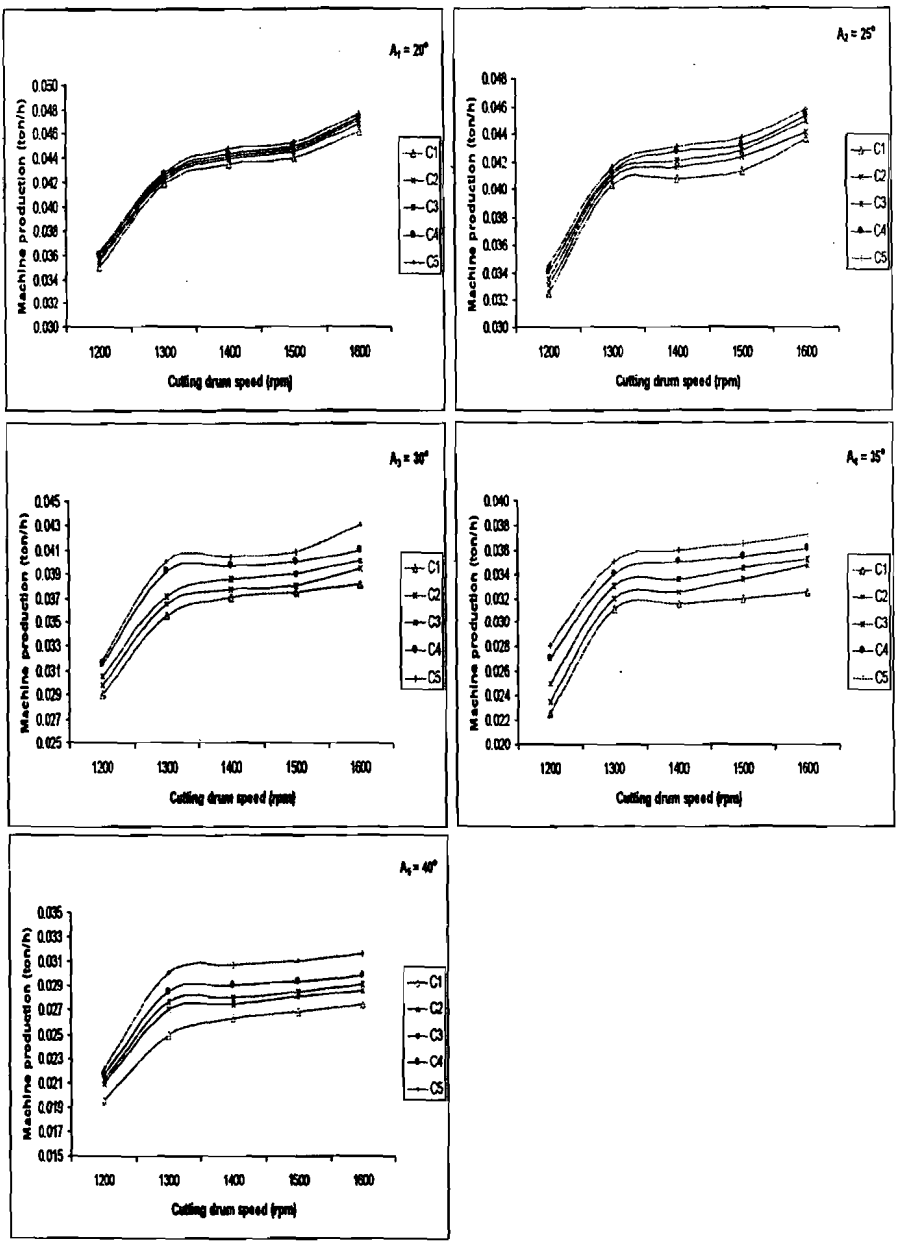

Fig (3): Machine productivity as a function of cutting drum speed at different (A) knife edge angle (20°, 25°, 30°, 35° and 40°), (C) clearance distance (1,2,3,4, and 5mm), and 20.56% M_{cwb} for cotton stalks.

3-1-2-Fuel consumption:

Results illustrated in Fig. (4) show that fuel consumption increased with increasing the cutting drum speed. It is increased by an average 66.67% with increasing the cutting drum speed from 1200 to 1600rpm at 20° knife edge angle, 1mm clearance distance, and 20.56% M_{cwb} this may be due to increasing the number of cuts per unit time by increasing the cutting drum speed which required increasing in fuel consumption (**Sluman *et.al.* 2010**). It is, also, clear the fuel consumption increased with increasing knife edge angle. It increased by an average 16.67% with increasing knife edge angle from 20° to 40° at 1600rpm cutting drum speed, 1mm clearance distance, and 20.56 $M_{cub.}$ This may be due to increasing the friction forces (main resistance for cutting) on the knife edge with increasing the knife edge angle. Results also, showed that full consumption increased slightly with increasing the clearance distance. It increased by an average 6.25% with increasing the clearance distance from 1 to 5mm at 20°knife edge angle, 1600 rpm cutting drum speed, and 20.56% M_{cwb}.

The maximum and minimum rates of fuel consumption are given in table (2).

Table (2): Max. and Min. rate of fuel consumption, for cotton stalks.

Fuel consumption (L/h)	Engineering factors		
	Cutting drum speed (rpm)	Knife edge angle	Clearance distance (mm)
Max. = 0.48	1600	40°	5
Min. = 0.12	1200	20°	1

3-1-3- The required power:

Data for the required power (kw) in Fig. (5) show similar trend to that obtained previously for the fuel consumption where the required power increased with increasing the cutting drum speed, knife edge angle, and the clearance distance. It increased by an average 50.8% with increasing the cutting drum speed from 1200 to 1600 rpm at 30° knife edge angle, 1mm clearance distance, and 20.56% M_{cwb}. It, also, increased by an average 33.3% with increasing the knife edge angle from 20° to 40° at 1400 rpm cutting drum speed, and 1mm clearance distance. The required

power increased slightly by an average 6.21% with increasing the clearance distance from 1 to 5 mm at 20°knife edge angle and 1600 rpm. Maximum and minimum required power is given in Table (3).

Table (3): Max. and Min. required power, for cotton stalks.

Required Power (kW)	Engineering factors		
	Cutting drum speed (rpm)	Knife edge angle	Clearance distance (mm)
Max. = 1.328	1600	40°	5
Min. = 0.332	1200	20°	1

3-1-4- The specific consumed energy:

Fig. (6) shows that the specific consumed energy (kwh/ton) increased with increasing the cutting drum speed, knife edge angle and clearance distance. It increase by an average 56.1% with increasing the cutting drum speed from 1200 to 1600 rpm at 20° knife edge angle, 1mm clearance distance and 20.56% M_{cwb}. It, also, increased by an average 79.86% with increasing the knife edge angle from 20° to 40° at 1600 rpm cutting drum speed, 1mm clearance distance. In general, The specific consumed energy, also, increased slightly by increasing the clearance distance. It increased by an average 3.4% with increasing the clearance distance from 1mm to 5mm at 20° knife edge angle and 1600 rpm cutting drum speed. The maximum and minimum specific consumed energy are given in table (4).

Table (4): Max. and Min. specific consumed energy, for cotton stalks.

Specific consumed energy (kWh/ton)	Engineering factors		
	Cutting drum speed (rpm)	Knife edge angle	Clearance distance (mm)
Max. = 41.89	1600	40°	5
Min. = 9.48	1200	20°	1

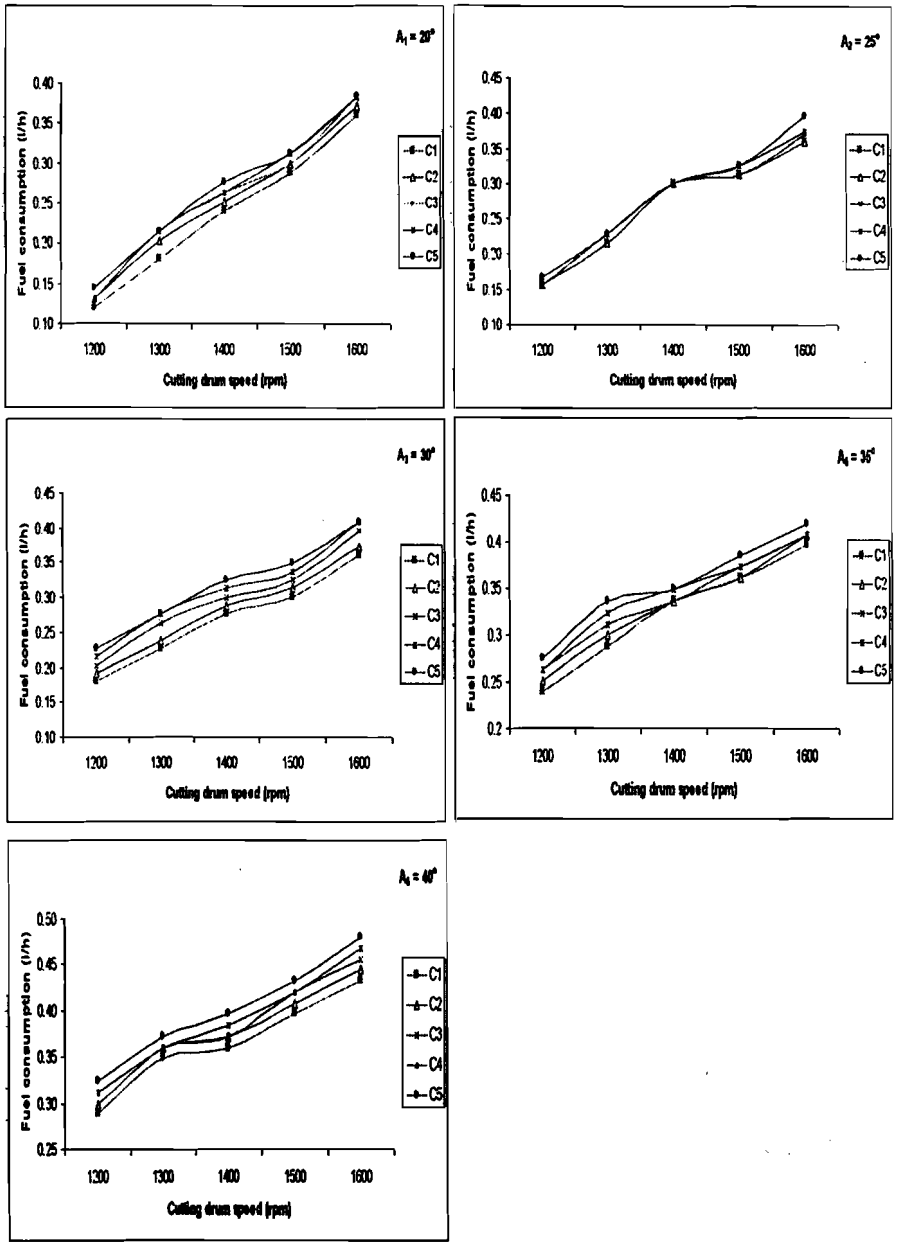

Fig (4): Fuel consumption as a function of cutting drum speed at different (A) knife edge angle (20°, 25°, 30°, 35° and 40°), (C) clearance distance (1,2,3,4, and 5mm), and 20.56% M_{cwb} for cotton stalks.

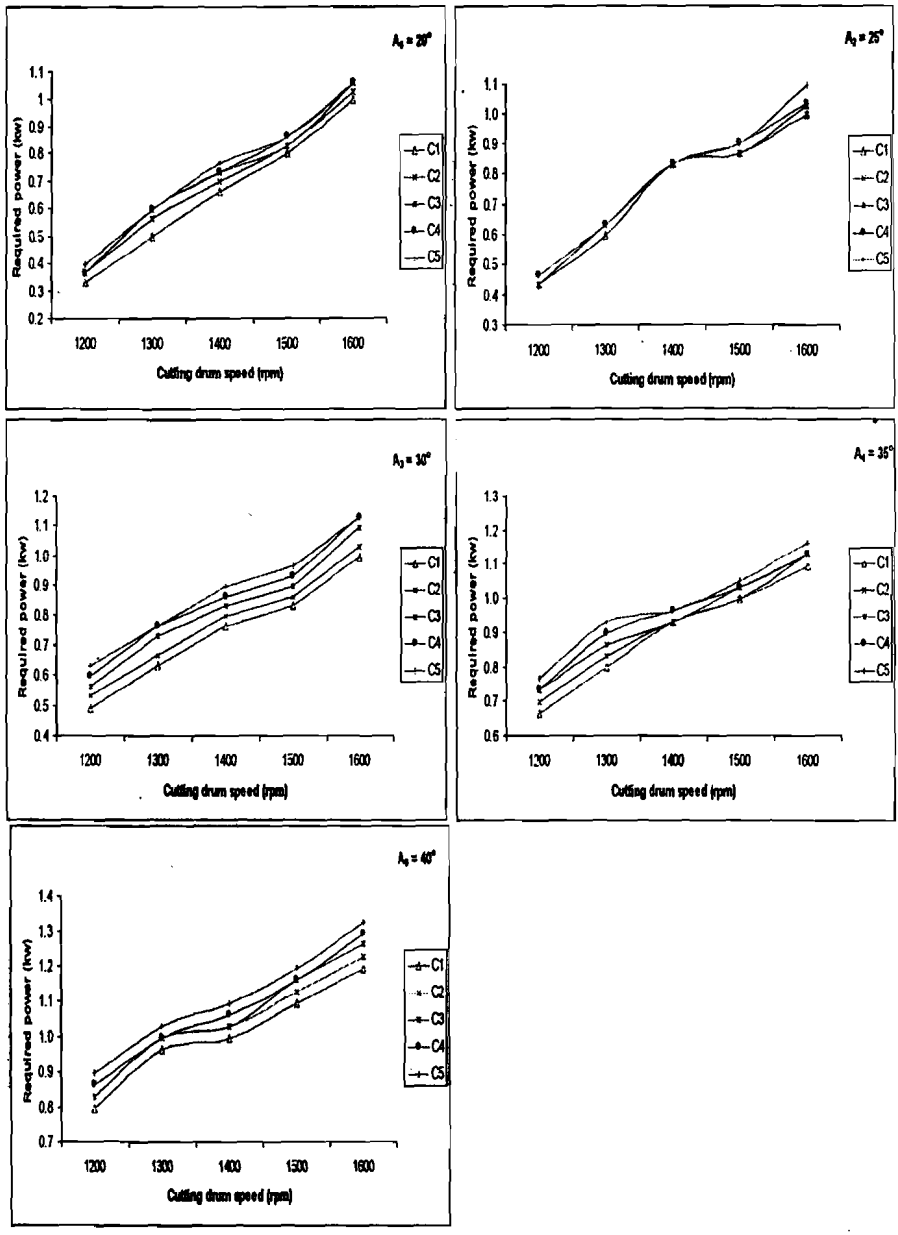

Fig. (5): The required power as a function of cutting drum speed at different (A) knife edge angle (20°, 25°, 30°, 35° and 40°), (C) clearance distance (1,2,3,4, and 5mm), and 20.56% M_{cwb} for cotton stalks.

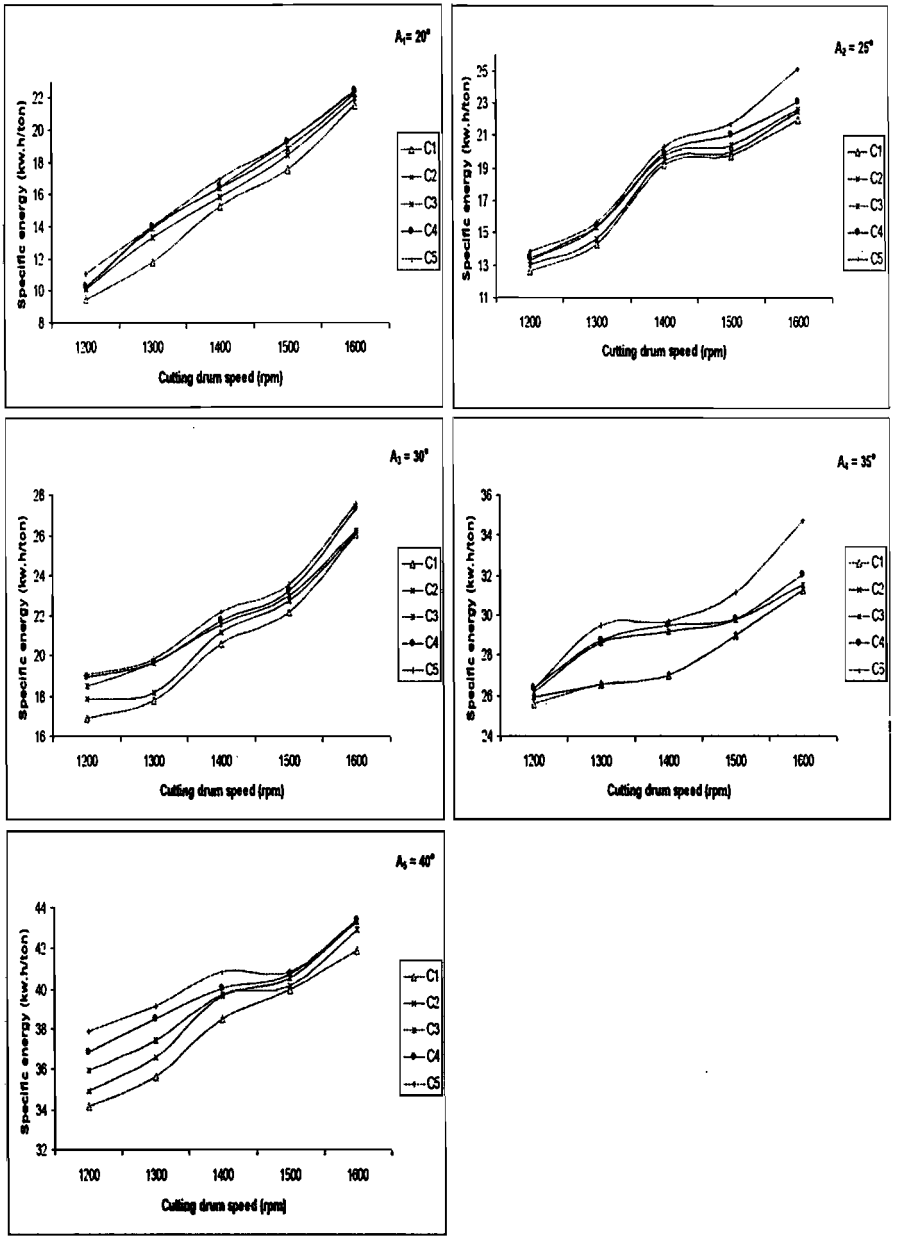

Fig. (6): The specific consumed energy as a function of cutting drum speed at different (A) knife edge angle (20°, 25°, 30°, 35° and 40°), (C) clearance distance (1,2,3,4, and 5mm), and 20.56% M_{cwb} for cotton stalks.

3-1-5- Cutting efficiency:

The relation between cutting efficiency and cutting drum speed at different knife edge angle (20°, 25°,30°, 35° and 40°), clearance distance (1,2,3,4, and 5mm) and 20.56% M_{cwb} is shown in Fig. (7). It is clear that the cutting efficiency increased with increasing the cutting drum speed. It increased by an average 23.6% with increasing the cutting drum speed from 1200 to 1600 rpm at 20° knife edge angle, and 1mm clearance distance. Such increase was due to the increase in the number of cuts per unit time which increased the weight of suitable cutting length, less than 5mm **(Sluliman *et. al.*, 2010).**

It can be, also, noticed that the cutting efficiency decreased with increasing the knife edge angle. The cutting efficiency decreased by an average 41.82% with increasing the knife edge angle from 20° to 40° at 1600 rpm cutting drum speed and 1mm clearance distance. It is, also, obvious that the cutting efficiency decreased with increasing the clearance distance. It decreased by an average 11.12% with increasing the clearance distance from 1 to 5mm at 20° knife edge angle, and 1600 rpm cutting drum speed. The maximum and minimum cutting efficiency are given in table (5).

Table (5) : Max. and Min. cutting efficiency for cotton stalks.

Cutting efficiency (%)	Engineering factors		
	Cutting drum speed (rpm)	Knife edge angle	Clearance distance (mm)
Max. = 67.70	1600	20°	1
Min. = 24.91	1200	40°	5

3-1-6- Cost estimation:

The cost per hour of operation of the cutting machine is estimated using equation (7) at the best cutting efficiency (67.7%) where the fuel consumption = 0.36 l/h, and the productivity = 0.0462 ton/h

Cost = 6.94 L.E./h

Or cost = $(6.94\ LE/h)/0.0462 = 150.23\ LE/Ton$

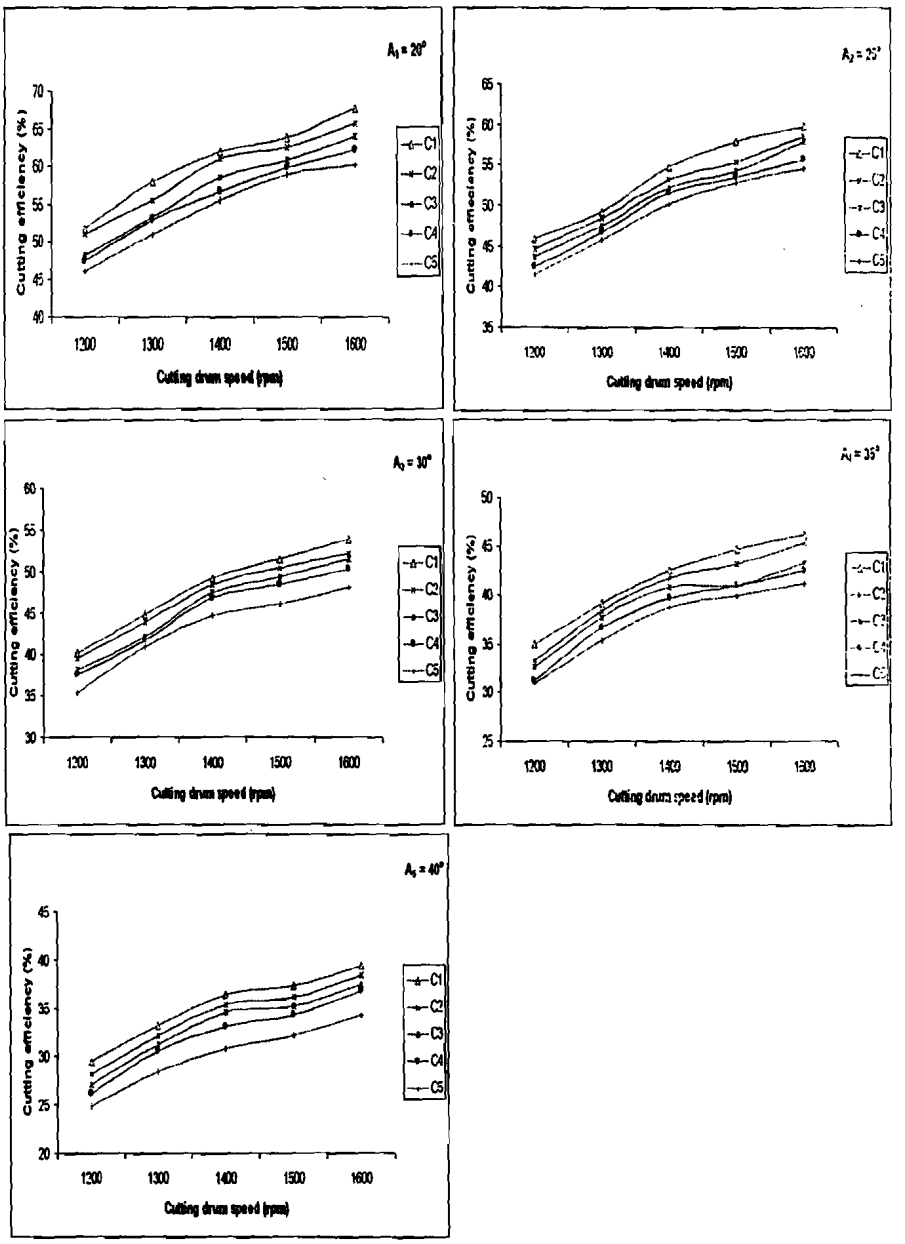

Fig. (7): Cutting efficiency as a function of cutting drum speed at different (A) knife edge angle (20°, 25°, 30°, 35° and 40°), (C) clearance distance (1,2,3,4, and 5mm), and 20.56% M_{cwb} for cotton stalks.

Data for corn stalks and rice straw show similar trend to that obtained previously for cotton stalks, so the main results would be presented next:-

3-2- Corn stalks

Results for corn stalks (25.64% M_{cwb}) showed that:-

3-2-1- Machine Productivity:

Machine productivity increased by an average 34.66% with increasing the cutting drum speed from 1200 to 1600rpm, at 20° knife edge angle, 1mm clearance distance, and 25.64% M_{cwb}. They, also, show that productivity decreased with an average 31.72% with increasing the knife edge angle from 20° to 40° at 1600rpm cutting drum speed and 1mm clearance distance. It can be also noticed that there was slight increase of the machine productivity with increasing the clearance distance. It increased by an average 4.60% with increasing the clearance distance from1 to 5mm at 1600rpm cutting drum speed, 20° knife edge angle, and 25.64% M_{cwb}. Maximum and minimum rate of machine productivity at 25.64% M_{cwb} are given in Table (6).

Table (6): Max. and Min. rate of machine productivity, for corn stalks.

Productivity (ton/h)	Engineering factors		
	Cutting drum speed (rpm)	Knife edge angle	Clearance distance (mm)
Max. = 0.0499	1600	20°	5
Min. = 0.0175	1200	40°	1

3-2-2- Fuel consumption:

Fuel consumption increased by an average 52.17% with increasing the cutting drum speed from 1200 to 1600rpm at 20° knife edge angle, 1mm clearance distance, and 25.64% M_{cwb}. It is also clear that fuel consumption increased with increasing knife edge angle. It increased by an average 39.47% with increasing knife edge angle from 20° to 40° at 1600rpm cutting drum speed, 1mm clearance distance, and 25.64 M_{cub}. This may be due to increasing the friction forces (main resistance for cutting) on the knife edge with increasing the knife edge angle. Results also, showed that full consumption increased slightly with increasing the clearance distance. It increased by an average 14.81% with increasing the

clearance distance from 1 to 5mm at 20°knife edge angle, 1600 rpm cutting drum speed, and 25.64% M_{cwb}.

The maximum and minimum rates of fuel consumption are given in table (7).

Table (7): Max. and Min. rate of fuel consumption, for corn stalks.

Fuel consumption (L/h)	Engineering factors		
	Cutting drum speed (rpm)	Knife edge angle	Clearance distance (mm)
Max. = 0.504	1600	40°	5
Min. = 0.132	1200	20°	1

3-2-3- The required power:

The required power increased by an average 42.37% with increasing the cutting drum speed from 1200 to 1600 rpm at30° knife edge angle, 1mm clearance distance, and 25.64% M_{cwb}. It, also, increased by an average 45.18% with increasing the knife edge angle from 20° to 40° at 1400 rpm cutting drum speed, and 1mm clearance distance. The required power increased slightly by an average 14.84% with increasing the clearance distance from 1 to 5 mm at 20°knife edge angle and 1600 rpm. Maximum and minimum required power are given in Table (8).

Table (8) : Max. and Min. required power, for corn stalks

Required Power (kW)	Engineering factors		
	Cutting drum speed (rpm)	Knife edge angle	Clearance distance (mm)
Max. = 1.394	1600	40°	5
Min. = 0.365	1200	20°	1

3-2-4- The specific consumed energy:

The specific consumed energy (kWh/ton) increased by an average 26.77% with increasing the cutting drum speed from 1200 to 1600 rpm at 20° knife edge angle, 1mm clearance distance and 25.64% M_{cwb}. It, also, increased by an average 58.74% with increasing the knife edge angle from 20° to 40° at 1600 rpm cutting drum speed, 1mm clearance distance. In general the specific consumed energy, also, increased slightly by increasing the clearance distance. It increased by an average 10.75 % with

increasing the clearance distance from 1mm to 5mm at 20° knife edge angle and 1600 rpm cutting drum speed. The maximum and minimum specific consumed energy are given in table (9).

Table (9) Max. and Min. specific consumed energy, for corn stalks.

Specific consumed energy (kWh/ton)	Engineering factors		
	Cutting drum speed (rpm)	Knife edge angle	Clearance distance (mm)
Max. = 47.64	1600	40°	5
Min. = 11.73	1200	20°	1

3-2-5- Cutting efficiency:

The cutting efficiency increased by an average 12.46% with increasing the cutting drum speed from 1200 to 1600 rpm at 20° knife edge angle, and 1mm clearance distance. It can be also noticed that the cutting efficiency decreased with increasing the knife edge angle. The cutting efficiency decreased by an average 42.52% with increasing the knife edge angle from 20° to 40° at 1600 rpm cutting drum speed and 1mm clearance distance. It is, also, obvious that the cutting efficiency decreased with increasing the clearance distance. It decreased by an average 9.22% with increasing the clearance distance from 1 to 5mm at 20° knife edge angle, and 1600 rpm cutting drum speed. The maximum and minimum cutting efficiency are given in table (10).

Table (10) : Max. and Min. cutting efficiency for corn stalks.

Cutting efficiency (%)	Engineering factors		
	Cutting drum speed (rpm)	Knife edge angle	Clearance distance (mm)
Max. = 47.59	1600	20°	1
Min. = 17.88	1200	40°	5

3-2-6- Cost estimation:

The cost per hour of operation of the cutting machine is estimated using equation (7) at the best cutting efficiency (47.59%) where the fuel consumption = 0.276 l/h, and the productivity = 0.0476 ton/h

Cost = 6.83 L.E./h

Or cost = $(6.83\ LE/h)/0.0462 = 147.83\ LE/Ton$

3-3- Rice Stalks

The obtained results for rice straw showed that:-

3-3-1- Machine Productivity:

Machine productivity increased by an average 9.09% with increasing the cutting drum speed from 1200 to 1600rpm, at 20° knife edge angle, 1mm clearance distance, and 14.8% M_{cwb}. They, also, show that productivity decreased with an average 48.18% with increasing the knife edge angle from 20° to 40° at 1600rpm cutting drum speed and 1mm clearance distance. It can be, also, noticed that there was slight increase of the machine productivity with increasing the clearance distance. It increased by an average 7.56% with increasing the clearance distance from1 to 5mm at 1600rpm cutting drum speed, 20° knife edge angle, and 14.8% M_{cwb}. Maximum and minimum rate of machine productivity at 14.8% M_{cwb} are given in Table (11).

Table (11): Max. and Min. rate of machine productivity, for rice stalks.

Productivity (ton/h)	Engineering factors		
	Cutting drum speed (rpm)	Knife edge angle	Clearance distance (mm)
Max. = 0.0595	1600	20°	5
Min. = 0.0240	1200	40°	1

3-3-2- Fuel consumption:

Fuel consumption increased by an average 66.66% with increasing the cutting drum speed from 1200 to 1600rpm at 20° knife edge angle, 1mm clearance distance, and 14.8% M_{cwb}. It is also clear that fuel consumption increased with increasing knife edge angle. It increased by an average 36.17% with increasing knife edge angle from 20° to 40° at 1600rpm cutting drum speed, 1mm clearance distance, and 14.8% M_{cub}. This may be due to increasing the friction forces (main resistance for cutting) on the knife edge with increasing the knife edge angle. Results also, showed that full consumption increased slightly with increasing the clearance distance. It increased by an average 9.09% with increasing the clearance distance from 1 to 5mm at 20°knife edge angle, 1600 rpm cutting drum speed, and 14.8% M_{cwb}.

The maximum and minimum rate of fuel consumption are given in table (12)

Table (12): Max. and Min. rate of fuel consumption for rice stalks.

Fuel consumption (L/h)	Engineering factors		
	Cutting drum speed (rpm)	Knife edge angle	Clearance distance (mm)
Max. = 0.624	1600	40°	5
Min. = 0.12	1200	20°	1

3-3-3- The required power:

The required power increased by an average 53.89% with increasing the cutting drum speed from 1200 to 1600 rpm at 30° knife edge angle, 1mm clearance distance, and 14.8% M_{cwb}. It, also, increased by an average 44.43% with increasing the knife edge angle from 20° to 40° at 1400 rpm cutting drum speed, and 1mm clearance distance. The required power increased slightly by an average 9.04% with increasing the clearance distance from 1 to 5 mm at 20°knife edge angle and 1600 rpm. maximum and minimum required power are given in Table (13).

Table (13): Max. and Min. required power, for rice stalks.

Required Power (kW)	Engineering factors		
	Cutting drum speed (rpm)	Knife edge angle	Clearance distance (mm)
Max. = 1.726	1600	40°	5
Min. = 0.332	1200	20°	1

3-3-4- The specific consumed energy:

The specific consumed energy (kWh/ton) increase by an average 63.31% with increasing the cutting drum speed from 1200 to 1600 rpm at 20° knife edge angle, 1mm clearance distance and 14.8% M_{cwb}. It, also, increased by an average 66.92% with increasing the knife edge angle from 20° to 40° at 1600 rpm cutting drum speed, 1mm clearance distance. In general, the specific consumed energy, also, increased slightly by increasing the clearance distance. It increased by an average 1.63% with increasing the clearance distance from 1mm to 5mm at 20° knife edge

angle and 1600 rpm cutting drum speed. The maximum and minimum specific consumed energy are given in table (14).

Table (14): Max. and Min. specific consumed energy, for rice stalks.

Specific consumed energy (kWh/ton)	Engineering factors		
	Cutting drum speed (rpm)	Knife edge angle	Clearance distance (mm)
Max. = 54.73	1600	40°	5
Min. = 6.64	1200	20°	1

3-3-5- Cutting efficiency:

The cutting efficiency increased by an average 27.25% with increasing the cutting drum speed from 1200 to 1600 rpm at 20° knife edge angle, and 1mm clearance distance.

It can be also noticed that the cutting efficiency decreased with increasing the knife edge angle. The cutting efficiency decreased by an average 37.14 % with increasing the knife edge angle from 20° to 40° at 1600 rpm cutting drum speed and 1mm clearance distance. It is, also, obvious that the cutting efficiency decreased with increasing the clearance distance. It decreased by an average 8.58% with increasing the clearance distance from 1 to 5mm at 20° knife edge angle, and 1600 rpm cutting drum speed. The maximum and minimum cutting efficiency are given in table (15).

Table (15): Max. and Min. cutting efficiency for rice stalks.

Cutting efficiency (%)	Engineering factors		
	Cutting drum speed (rpm)	Knife edge angle	Clearance distance (mm)
Max. = 62.75	1600	20°	1
Min. = 20.92	1200	40°	5

3-3-6- Cost estimation:

The cost per hour of operation of the cutting machine is estimated using equation (7) at the best cutting efficiency (62.75%) where the fuel consumption = 0.36 l/h, and the productivity = 0.0550 ton/h

Cost = 6.94 L.E./h

Or cost = $(6.94\ LE/h)/0.0462 = 150.23\ LE/Ton$

4. CONCLUSION

The performance of an experimental crop residues cutting machine is evaluated to determine the energy requirements for cutting operation of three different crop residues (cotton stalks, corn stalks and rice straw). The effect of cutting drum speed, knife edge angle, and clearance distance on the machine productivity, fuel consumption, required power, specific consumed energy, cutting efficiency and the estimated cost of machine operation were, also, discussed. The machine evaluated at five cutting drum speeds 1200, 1300, 1400, 1500 and 1600 rpm (8.29, 8.98, 9.3.68, 10.37 and 11.06 m/s); five knife edge angle (20°, 25°, 30°, 35° and 40°), and five clearance distance (1, 2, 3, 4 and 5mm). The results, at 1600 rpm cutting drum speed, 20° knife edge angle and 1mm clearance distance, showed that the machine productivity, fuel consumption, required power, specific consumed energy, maximum cutting efficiency and estimated cost of machine operation were:

- for cotton stalks (20.56% Mcwb): 0.0476 ton/h, 0.48 L/h, 1.328kw, 41.89 kwh/ton, 67.70%, and 150.23 LE/ton, respectively;
- for corn stalks (25.64% Mcwb) : 0.0499 ton/h, 0.504 l/h, 1.394 kw, 47.64 kwh/ton, 47.59% and 147.83 LE/ton, respectively; and
- for rice straw (14.8% Mcwb): 0.0595 ton/h,0.624 L/h, 1.726 kw,54.73 kwh/ton, 62.75%, and 150.23 LE/ton, respectively.

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الملخص العربى

الطاقه المطلوبه لعملية قطع مخلفات بعض محاصيل الحقل

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معظم مخلفات المحاصيل الزراعية تكون ناتجه عن عمليات الحصاد. وهناك كميات هائلة من مخلفات المحاصيل التى يتم إنتاجها سنوياً فى مصر والتى تسبب مشكلات خطيرة تواجه المنتجين الزراعيين. وتعتبر عملية تقطيع مخلفات المحصول لقطع صغيرة طريقه فعاله وبسيطه لكى تكون مناسبة للتخزين والتداول والتدوير لكى تتناسب مع الاستخدامات العديدة. وفى هذه الدراسة تم تقييم اداء ماكينة تجريبية لتقطيع مخلفات المحاصيل لتحديد الطاقة المطلوبة لعملية القطع لثلاث مخلفات محاصيل وهى (حطب القطن – سيقان الذرة - وقش الأرز) كما تمت مناقشة تأثير السرعة الدورانيه لإسطوانة السكاكين وزاوية حافة سكين القطع ومسافة الخلوص، إنتاجية الألة، استهلاك الوقود، القدره المطلوبة، الطاقه النوعيه المستهلكه، كفاءة القطع، وتكلفة تشغيل الألة.

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وتم تقييم الألة بإستخدام خمسة سرعات للقطع (١٢٠٠ – ١٣٠٠ – ١٤٠٠ – ١٥٠٠ – ١٦٠٠ لفة فى الدقيقة او ٨,٢٩ – ٨,٩٨ – ٩,٦٨ – ١٠,٣٧ – ١١,٠٦ م/ث) وخمس زوايا لحافة السكين (٢٠- ٢٥ – ٣٠ - ٣٥- ٤٠ درجة) وخمسة مسافات للخلوص (١-٢-٣-٤- ٥مم). وكانت النتائج عند سرعة قطع ١٦٠٠ لفة فى الدقيقة، وزاوية حافة السكين ٢٠ درجة ومسافة خلوص ١مم كما يلى:

- بالنسبه لحطب القطن: كانت نسبة الرطوبة فى محصول القطن٢٠,٥٦% وأقصى إنتاجية للآلة كانت ٠,٠٤٧٦طن/ساعة وأقصى معدل إستهلاك وقود للآلة كان ٠,٤٨ لتر/ساعة وأقصى قدرة مطلوبة كانت ١,٣٢٨ كيلووات وأقصى طاقة نوعية مطلوبة كانت ٤١,٨٩ كيلو وات فى الساعة/الطن وأقصى كفاءة تقطيع للآلة كانت ٦٧,٧% وكانت تكلفة الطن ١٥٠,٢٣ جنيه .

- بالنسبه لسيقان الذرة: كانت نسبة الرطوبة فى محصول الذرة ٢٥,٦٤% وأقصى إنتاجية للآلة كانت ٠,٠٤٩٩ طن/ساعة وأقصى معدل استهلاك وقود للآلة كان ٠,٥٠٤ لتر/ساعة وأقصى قدرة مطلوبة كانت ١,٣٩٤ كيلو وات واقصى طاقة نوعية مطلوبة كانت ٤٧,٦٤ كيلو وات فى الساعة/الطن واقصى كفاءة تقطيع للآلة كانت ٤٧,٥٩% وكانت تكلفة الطن ١٤٧,٨٣ جنيه.

- بالنسبه لقش الأرز: كانت نسبة الرطوبة فى محصول الأرز ١٤,٨% وأقصى إنتاجية للآلة كانت٠,٠٩٥٩ طن/ساعة وأقصى معدل استهلاك وقود الآلة كان ٠,٦٢٤ لتر/ساعة وأقصى قدرة مطلوبة كانت ١,٧٢٦ كيلو وات وأقصى طاقة نوعية مطلوبة كانت ٥٤,٧٣ كيلو وات فى الساعة/الطن وأقصى كفاءة تقطيع للآلة كانت ٦٢,٧٥% وكانت تكلفة الطن ١٥٠,٢٣ جنيه.