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Research Article

A Comparative Study of Different Rice Straw Recycling Systems

Karam El-Hag Hassan [1], El-Khawaga, S.E[2] and Mohamed El-didamony [3]*

[1] Agricultural Research Center, Mechanized agriculture sector ,Giza, Dokki, Egypt.
[2] Agricultural Engineering Research Institute, Giza, Dokki, Egypt.
[3] Tanta University, Faculty of Agriculture, Agricultural Engineering Department. Egypt; el-didamony@agr.tanta.edu.eg
* Correspondence: agr.mid@gmail.com.

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Abstract:
There are three main system of rice straw recycling. The first one includes manual collection of rice straw stalks, transporting it to the collection centers, chopping it, and pressing of chopped rice straw into bales, respectively. Meanwhile the second recycling system includes two models, in the first model, rice straw is pressed in small rectangular bales, transporting it to the collection centers, chopping it and pressing chopped rice straw into bales while in the second type, rice straw stalks are pressed in large round bales, transported to the collection centers, chopped and pressed into bales respectively. The third recycling system includes collecting and chopping rice straw stalks directly in the field in which rice straw is transported to the collection centers and pressed into bales respectively. The aim of the current study was achieved by identifying some performance indicators which were: time and energy requirements and number of machines required to deliver the product on final form. The experiment was conducted at El-sinblaween Center El –Dakhlia Government (31°22'60" E, longitude, 31°02'60";N, latitude; and 11.21, m height) in northeast Egypt. During summer season 2022.Three different systems of rice straw recycling into chopped bales were compared in this study. The results indicated that the energy, time, labor, costs and number of machines required were 29.7 kW.h/Mg, 27.32 h/Mg, 31 Labor. h/Mg, 910 L.E/Mg and 6 machines required for the first system respectively. Meanwhile for the second system, these values were 28.83 kW.h/Mg, 5.25 h/Mg, 10 laborer. h/Mg,631.8L.E/Mg and 8 machines required for small rectangular bales respectively while for large round bales the records were 35.76 kW.h/Mg, 2.39 h/Mg, 7 laborer. h/Mg, 601.4 L E/Mg and 12 machines required respectively and for third system they were 27.02 kW.h/Mg, 1.54 h/Mg, 3 laborer. h/Mg, 517.25 L.E/Mg and 6 machines required respectively.

1. Introduction

Rice straw is a by-product of harvesting paddy. About 90% of rice field is harvested by a combine harvester. With the progress of the rice production systems for a long time, the amount of straw is increasing. The amount of rice straw produced globally in 2008, 2013, and 2018 was found to be 620, 731, and 1000 million tons/year (Nguyen, et al., 2018; Gummert, 2013; Sarkar and Aikat, 2013). And with the expected increase in global demand for rice by 28% in 2050, production will be 1280 million Mg (Zhang, et al., 2021). In Egypt the amount of agriculture residues was about 50 million Mg in 2021 from which rice straw represent about 5.2 million Mg with an average production of 5.73 million tons. That huge amount of rice straw must be collected as soon as possible after crop harvesting to avoid delaying the following field operations and for reducing weather risks (EEAA, 2021, Elbateh, 2020). Some useful applications of rice straw as; organic fertilizer, cattle feedstock, chicken straw, soil incorporation, mushroom production, power generation, industry of wood, paper and building materials (Zaghloul, et al., 2018). However only about 20% of rice straw was used for purposes such as producing ethanol, paper, fertilizers and fodders and the remaining amount is either removed from the field, in situ burned, piled or spread in the field, incorporated in the soil, or used as mulch for the following crop (Hanafi et al., 2012). Burning one Mg of rice straw will produce about 56 kg of carbon monoxide (CO). Therefore, if only 1 million Mg were burned annually, the total amount of carbon monoxide (CO) would have reached 56,000 Mg. This will actually lead to an increase in air pollution, which is the main cause of cancer (California Agricultural Magazine, 1991).There are great efforts towards recycling rice straw to reduce the environmental pollution during rice threshing season (El-Gindy, et al., 2009). The use of rice straw as animal feed leads to an increase in the diversity of animal feed sources, but however, it is known that rice straw has low nutritional quality and digestibility as a result of high content of cellulosic compounds. Whereas, the use of rice straw without treatment can lead to a reduction in livestock productivity and even cause losses in the livestock sector. While, with cutting rice straw, they are utilized in animal feed, fertilization, biogas production, or other environmentally friendly industries (Hashem et al., 2022).

There are three different ways to handle straw that has been left lying around in a field: burn it, recycle it or return it directly to the field, as shown in Fig. (1) (Huang, et al., 2019). The labor required for manual picking and packing per wheat straw of one feddan after harvesting with combine was 6 labors with 9 working hour per day then the time required per one feddan was 54 hours.

Fig.1. Various approaches to handling scattered straw in the field.

They also, added that the average losses of straw was 13.7% and high cost of picking and packing of straw after harvesting was 165 L.E/fed (El-Danasory and Imbabi, 1998). The density of crop residues ranges from 65-75 kg/m3. The bale density ranges between 150-180 kg/m^3. The reported densification cost is 80-100 Rs /Mg (298 – 372 L.E/Mg), transportation cost for bulk feed is 408 Rs /Mg (178 L.E/Mg) and high-density forage including bales cost is 196 Rs/ton (Gupta, et al., 1994).

Baling is a feasible method to collect, transport, store straw, effective to reduce costs and viable (Zhao, et al., 2018). Collecting and baling straw in the field was considered a more convenient straw management technique to make the field free of loose straw without burning the straw in the field. A baler has been tested on 50 hectares of both rice and wheat fields with a forward speed of 2.7 km/h with a collecting width of 124 cm. The number of tied bales of rice straw obtained per hour was 181 with a bale density and weight of 200 kg/m3 of 22 kg respectively (Mangaraj & Kulkarni, 2011). Balers can be divided into round and square balers according to the working principle and the shape of straw bale. The field capacity of straw baler increased from 0.34 – 0.85 ha/h, if operated after use of shrub master and hay rake operation (Kumar, et al., 2020).

The average costs of recycling a ton of rice straw for the purpose of compressing in bales in the sample of the study in Dakahlia and Damietta governorates in the 2019/2020 season was 118.5 L.E for mechanical; 140.5 L.E for human labor; total 259 L.E (Hamza et al., 2021). The total cost of recycling one ton of straw bales into chopped straw was 160 pounds (100 L.E for labor, 60 L.E for a chopper) (Elbateh, 2020). The highest value of baling total cost of 227.5 L.E / ton was recorded at a feeding rate of 1.5 ton/h (Afify, et al., 2002). When compared between a square baler with 1.65 m pick-up gatherer and round baler with a pick-up width of 0.8 m in the Philippines. Shown results that The cost is significantly lower for the square baler by 4.3 times, which is US$20.95 and US$110.64 per ton, respectively, for square and round balers (Balingbing, et al., 2020). In Vietnam, Shown results that with the application of mechanical straw gathering method, collection cost is much reduced from US$50/ton for manual collection and US$19/ton for collection using the baler (Nghi, et al., 2015). (Kadam, et al., 2000) studied harvesting systems and provided an analysis of operating parameters such as straw moisture, density, storage, and optimal number of transport units in California. they concluded that 550 t dÿ1 of straw can be accessed at an estimated net delivered cost of about US $20/ ton (dry).

(El-Sayed, et al., 2019) developed a feeding unit suitable for small barns is. The results indicated that the maximum percentage in the soften cutting length > 5 cm was 92.82 % the maximum power consumption value (6.85 Kw.h/ton) was obtained at the lowest cutting speed of 7.540 m/s, feeding rate of 0.85 ton/h and knife interference of 5 mm. The maximum operation cost was 121.20 L.E/ton with the same factors. The results indicated that the chopping process requires minimum values of energy and cost of 8.9 kW.h/ton and 79.7LE /ton respectively, while the baling process requires minimum values of 5.67 kW.h /ton and 98.5LE/ ton (Abdelhamid, 2021). Developed a large round shredder with a capacity of four large round bales and hay can be transported by conveyor to a temporary store. The stationary unit consists of a bale collector with a capacity of four bales, a bale cutter, and a conveyor for shredded products. The results indicate that bales can be shredded at a rate of 48.5 kg/min with energy requirement of 4.06 kW.h/ton and hay lengths (% weight) <10mm, 10-50 mm and>50mm were 16.5%, 19.7% and 63.8% respectively (Messner et al., 1991). (Abd El- Mottaleb, 2002) compared between pick up, stationary and round baler. He found that the pickup of rice straw requires minimum values of fuel, power and energy of 7.5 L/fed., 13.8 kW and 20.3 kWh/fed respectively, while maximum values were observed using both round balers of 14 L/fed, 27kWand 38kWh/fed of rice straw and stationary baler 28 L/fed., 19 kW and 76 kWh/fed of rice straw.

(Awad, et al., 2022) constructed a combined machine for collecting and chopping rice straw for lengths preferred in feeding ruminants. The combined machine comprises three main units: a picking up unit, a chopping unit, and a takeout unit. The obtained results indicated that the consumed specific energy was 12.125 kW.h/ton with field capacity of 1.8 ton/h and drive the tractor at a forward speed of

1.3 km /h. The total operating cost of the combined machine is lower than the traditional methods by about 49.84%. Cost were about $205 and $102.82 per ha for the traditional method and the combined machine respectively.. A multi-function rice combine harvester was designed for harvesting and hay bales. This multifunctional combine harvester can reduce the energy consumption required to harvest rice and simplify the harvesting and baling process (Tang & Cheng, 2017).

So, the present study aims to compare different rice straw recycling systems to develop the existing machines which lead to improve specifications required for the final product, minimize the operation time and cost, maximize their utilization and reduce the time needed to dispose of previous crops residues to prepare the land for the next crops.

2. Materials and Methods

The experiment was conducted at El-sinblaween Center, Dakhlia Government (31°22'60" E, longitude, 31°02'60";N, latitude; and 11.21, m height) in northeast Egypt. during summer season of 2022.Three different systems of rice straw recycling were compared in this study.

The physical properties of rice straw stalks measured during summer season 2022 and listed in Table (1):

Table.1. Physical properties of rice straw stalks.

varieties	Average of diameter (mm)			Average of Length (mm)	Average of moisture content (MC)	Average of straw weight per linear meter (g)	Production Mg / Fad
	base	center	top				
Sakha 101	4.3	3.5	1.8	80	15.5%	900	2.5
Sakha 108	5.2	3.5	1.8	90	22%	1327	3.7
Giza 177	4.5	3.6	1.6	95	16%	1040	2.9
Sakha super 300	5.4	3.9	1.9	105	20%	1435	4
average of varieties	4.85	3.65	1.77	92.5	18.375%	1178	3.275

Rice was harvested at 10 cm above the ground by a combine harvester (Yanmar-48hp). Combine harvester distributes the rice straw in windrows separated with 1.2 m width. In the comparative study variety Sakha 101 was used. After natural dried rice straw stalks and when its moisture content reached to 15.5 %, the stalks of rice straw has been processed to be recycled into chopped straw bales.

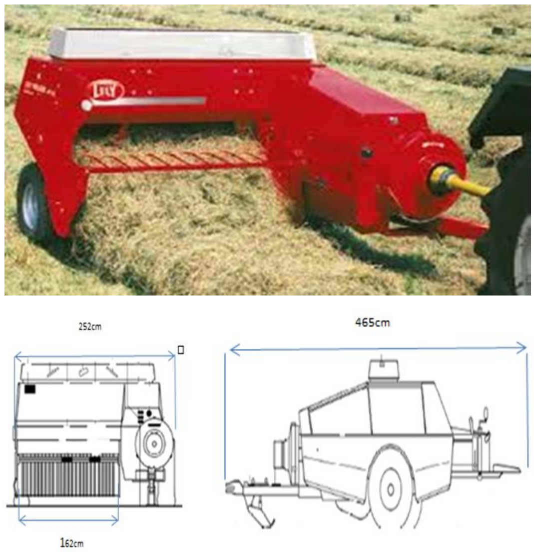
Collecting straw in the field:

1-1 Manual collecting system of rice straw after harvesting.

Rice straw was manually collected by 8 laborers per fadden at rate of 8 working hour per day and was placed on the surface of the land in bundles about 10-15 cm diameter, then it was placed in a heap in the corner of the field.

1-2 Baling machines. Two types of balers were used.

- Pressing rice straw in small rectangular bales. Lely Welger Baler model AP530 (Fg.2) was used in the comparative study, with a 1.62 m pickup device width. The technical specification of the Lely Welger pickup baler model AP530, specification of required tractor and specification of bale are listed in Table 2. Kubota tractor M5000, 37.3 KW/50 hp, diesel engine with four-wheel drive work at P.T.O speed of 540 rpm was used to operate the baler. After making bales, the stack of bales on the side of road was required. Where in this case, the individual straw bales are picked up from the field, and placed at the side of the field to be stacked to facilitate the pick-up operation of bales for transporting. This operation was carried out by two labors.



Elevation Side view

Fig.2. Lely Welger pickup baler model AP530

Table (2): Technical specification of the Lely Welger pickup baler model AP530

specification of Baler	
Length (cm)	465
Width (cm)	252
Height (cm)	163
Pick-up working width (cm)	162
Weight (kg)	1700
Number of ram strokes (min.)	100
specification of required **Tractor**	
P.T.O. Speed, r.p.m.	540
Minimum power, KW/hp	26/35
specification of Bale	
Height x width (cm^2)	36 x 48
Length (cm) adjustable	50-120
Bale weight (kg)	12-35

Pressing rice straw in large round bales.

Vicon baler model RF 119 (Fg.3) with 167cm width of Pick-up device was used in the comparative study. The technical specification of the Vicon Baler model RF 119, specification of required for the tractor and specification of bale are presented in Table 3.

Kubota tractor M9000, 60.4 kW/81hp, diesel engine, four-wheel drive work at P.T.O speed of 540r.p.m was used to operate the baler

Fig. (3): Vicon pickup baler model RF 119

Table (3): Technical specification of the Vicon pickup baler model RF 119.

specification of Baler	
Length (cm)	443
Width (cm)	235
Height (cm)	222
Pick-up working width (cm)	167
Empty Weight (kg)	1880
specification of required Tractor	
P.T.O. Speed, r.p.m	540
Minimum power, KW / hP	44.7 KW / 60hp
specification of Bale	
Bale-Ø from-to (cm)	125
Bale width (cm)	120 - 125
Bale weight to (kg	350

1-3 Combine pick up and chopping straw:

The combined machine (Fg.4) which was used in this study consists of three main units. Picking up unit, chopping unit, and chopped straw tank unit. The picking up unit consists of a control wheel located in the front, then the picking device, which includes 216 fingers with 4.0 cm length and 1.0 cm diameter. The cutting device includes a cylindrical chamber with a fixed knife and a drum supply with high-speed rotating knives. The takeout unit has a high-speed fan of 2400 rpm. The combined machine was powered by a 45kW tractor (Deutz-Fahr, 2WD) and P.T.O speed 540 r.p.m.

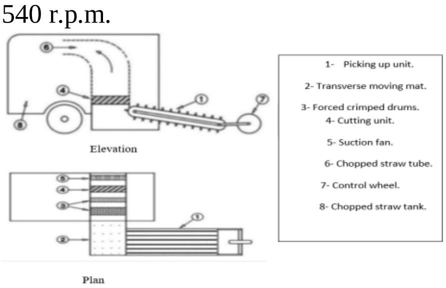


Fig. (4): Combine pick up and chopping straw.

2- Loading and unloading bales: The small bales and straw bundles were loaded and unloaded by two workers. While the large round bales were loaded and unloaded by a loader

(40 hp) 29.5 kW power.

3-Transporting the bales to collecting center: the transporting was achieved by simple flat-bed trailers drawn by tractor (Romany 75 hp / 55.9 kW).

4-Chopping the bales: A local made chopper (**Fg.5**) operated by Kubota tractor (M5000), 50 hp/ 37.3KW was only used for the first and second system; labors collected the straw and hand it to the chopper operator. This operation was carried out by five labors who unpacks the rice straw bales with full stems and feeds them through the platform to feeding device and the chopping drum that contains the knives to chop the rice straw, and from it to the outlet tube. The technical specifications of the local made chopper are shown in **Table 4**.

Fig. (5): local made chopper.

Table (4): Technical specification of the local made chopper.

specification of the local made chopper	
Feeding platform	It was made of iron sheet of450, 360, 4 and 20mm length, width, thickness and height, respectively. The feeding platform inclined angle is 15˚.
Feeding device	It consists of two counter-rotating rolls of 360 mm length diameter of 100mm, one of the rolls is curly and the other is smooth. which rotate in the opposite direction to pull the straw stems linked between them with a zipper that prevents the machine from turning when feeding
Chopping drum	It consists of a steel cylinder of 200mm diameter and 360mm length. Four steel cutting knives were installed on the cylinder with an inclination of 25˚.The fork dimensions were 360,5 and 50 mm length, width and thickness, respectively.
Transmission system	The chopping drum was operated using means of pulleys and belts which were powered using 50 hp/ 37.3KW tractor at 540 rpm P.T.O.

5- Pressing of chopped rice straw: The locally made stationary baler is shown in (**Fg.6**). The technical specifications of the baler, specification of required tractor and specifications of bale are showed in Table 4. A Romanian Tractor of 75 hp was used to operate the baler at P.T.O speed of 540 r.p.m. This operation was carried out by six labors that collect the chopped straw and hand it to baler operator. The rice straw stalks are placed before adding the chopped rice straw to the baler feeding chamber to forbid the chopped rice straw from fallen due to its small length.

Fig. (6): locally made stationary baler.

Table (5): Technical specification of the locally made stationary baler.

specification of Baler	
Length (cm)	560
Width (cm)	160
Height (cm)	175
Weight (kg) Empty	1800
plunger stroke (cm)	64cm
Number of ram plunger strokes (min.)	20 cycles per min
specification of required Tractor	
P.T.O. Speed, r.p.m	540
Power	55.9 kW /75 hp
specification of Bale	
Height x width (cm)	45×35
Length (cm)	100
Bale weight (kg)	35

Measuring Instruments

Electronic balance: An electronic scale (Japan make) was used for weighing samples in each category. Its scale ranged from 0 to 5 kg max., with an accuracy of 0.2 g.

Spring balance: A spring balance was used for weighing the chopped materials of rice straw. It has a range up to 75 kg max. And 0.5 kg accuracy.

Stop watch: To measure the net time taken to perform different operations.

Surveyor tape 30 meters: For measuring the dimension.

Sliding caliper: For measuring the length of chopped rice straw.

Hay-moisture tester: Model (HTM-1) ranged from 13 to 40% was used to

measure the moisture content of rice straw.

Measurements

Physical properties of rice straw: The Physical properties of rice straw stalks during harvest time were determined. Rice straw samples were selected randomly.

Dimension of Rice Straw stalks: The diameter of rice straw stalks (at base, center, and top) were measured in mm using vernier caliper (0.01mm accuracy) and length of rice straw stalks for the three tested varieties were measured in cm using Surveyor tape

Weight of rice straw stalks per linear meter: A linear meter of rice straw stalks on the windrows was taken randomly in ten places for four varieties to determine weight of straw stalks per linear meter.

Density: a sample of each of rice straw stalks; round and rectangular rice straw bales and chopped rice straw bales were weighed. The density was calculated by dividing sample weight by its volume.

Size requirements for storing: Size requirements for storing each of rice straw, round and rectangular rice straw bales and chopped rice straw bales were calculated using the following equation (1), El- Shal (2005):

$$S.R.S.B = \frac{S.Y.}{S.D.or\ B.D.} \quad \ldots\ldots\ldots\ldots. (1)$$

S.R.S.B. = Size requirements for storing bales, m³/fed;

S.Y. = Straw yield, kg/fed;

S.D.or B.D. = Rice straw or bale density, kg/m³.

But for the round rice straw bales, it is noted that this equation cannot be applied because the storage volume of the bale is larger than the calculated one (during storage there are spaces between the bales). This is one of the most important reasons for refusing to export straw in the form of Round bales. Therefore were calculated using the following equation:

$$S.R.S.B = \frac{(S.Y.)\times d^2 \times L}{m} \ldots\ldots\ldots\ldots\ldots \mathbf{(2)}$$

Where: **d**= diameter of round bale, **L**= length, of round bale, m= mass of round bale

Fuel consumption: The fuel consumption was measured by top-up method. Initially the tank was filled to the top and the operation was carried out. After the operation, the difference in the fuel level was used to measure fuel consumption.

Power requirement: It was calculated according to the principles and assumptions of (**Barger et al., 1963**).

$$P = \frac{F_c}{3600} \times \rho_f \times L.C.V \times 427 \times \eta_{th} \times \eta_m \times \frac{1}{75\times 1.36} \quad kW \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(3)$$

Or $P = 3.163\ F_c$ KW

Where,

F_c = Fuel consumption, L/h.

ρ_f= Density of the fuel (0.85 kg/ L for diesel fuel)

LCV = Lower calorific value of fuel (10000 kcaL/kg for diesel fuel).

427 = Thermo mechanical equivalent, kg.m/ kcal

η_{th} = Thermal efficiency of engine (40 % for diesel engine).

η_m =Mechanical efficiency of engine (80% for diesel engine)

Energy requirements: Specific energy requirements were estimated by using the following equation (3).

$$Energy = \frac{\text{Power consumption (kW)}}{\text{productivity,Mg.h}^{-1}}\ kWh.\ Mg^{-1} \cdots (4)$$

Labor Power =0.075 KW

Cost Analysis

To estimate the system cost the following equation, was used n: (EL-Awady, 1978)

$$c = \frac{p}{h}\left(\frac{I}{a} + \frac{I}{2} + t + r\right) + (\,1.2w.f.s\,) + \frac{m}{144} \ldots ..(5)$$

Where:

C = Hourly LE/h

P =Price of the machine, LE

h = Yearly working hours, h/year

a = Life expectancy of the machine,

i = Interest rate/year.

r =Repairs and maintenance ratio

w=Power, Hp

f =Specification fuel consumption, Lit/hp

s=Fuel price, LE/lit

m =Operator monthly salary.

1.2 =Factor accounting for lubrications

144 =the monthly average working hours

Labor cost = 150 LE /day (8-hour work)

The aim of current study was achieved by identifying some performance indicators which were: time, labor and energy requirements, number of machines required to deliver the product on final form, the economic operation cost.

3. Results and Discussion

The obtained results were discussed under the following topics:

Labor requirements (labor. h/Mg):

These tests were conducted to study the effect of recycling system on total number of labors requirements. The total number of labors during all the stages of baling operation for three systems are summarized in Table (6) and plotted in Fig. (7). the results indicated that total number of labors requirements have been affected by collecting methods. The highest number of labors 31 (labor. h/Mg) was observed with the manual collecting system while the second highest order 10 (labor. h/Mg was observed with rectangular baling system. However, the third order was obtained from round baling system and the lowest of 3 (labor. h/Mg) was obtained from Combine pick up and chopping straw system.

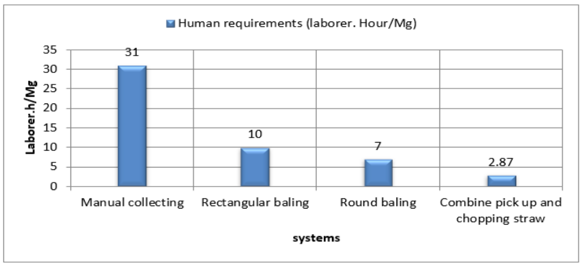


Fig. (7): Human requirements (laborer. h/Mg) for rice straw recycling systems into chopped bales.

Table (6) Human requirements (workers. h/Mg) for rice straw recycling systems into chopped bales.

System / Operation	Manual collecting	Baling straw		Combine pick up and chopping straw
		Rectangular baling	Round baling	
collecting	21.3	-	-	0.555 workers. hour/Mg In addition to the time consumed (0.666 laborer.h/Mg) for transport to the collection center
Raking	-	-	0.11	
Baling	-	0.43	0.2	
Roadsiding and stacking	-	1.33	-	
Loading	2	1	0.26	
Transport	0.5	0.5	0.57	
unloading	2	1	0.26	
Chopping	3.33	3.33	3.33	
Baling straw chopped	2	2	2	2
total	**31.13≈31**	**9.59≈ 10**	**6.73≈ 7**	**3.21≈ 3**

Time requirements (h/Mg):

Fig. (8) and Table (7) show the effect of recycling system on total time requirements per one Mg of chopped bales. The results showed that total time has been affected by collecting methods. It can be noticed that the highest time of 27.32 (h/Mg) was obtained from Manual collecting system while the second highest was 5.25 (hour/Mg) rectangular baling the lowest of 1.54 (h/Mg) was obtained from Combine pick up and chopping straw system.

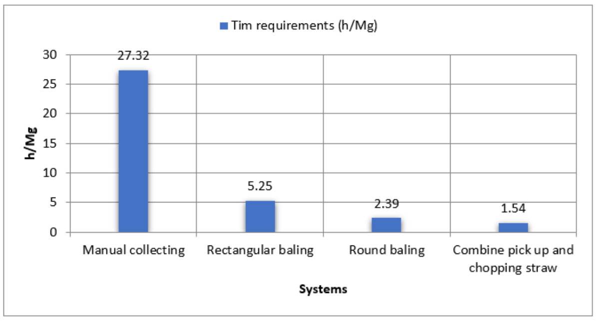


Fig. (8): Tim requirements (h/Mg) for rice straw recycling systems into chopped bales.

Table (7): Tim requirements (h/Mg) for rice straw recycling systems into chopped bales.

Operation \ System	Manual collecting	Baling straw: Rectangular baling	Baling straw: Round baling	Combine pick up and chopping straw
collecting	21.33	-	-	0.55h/Mg In addition to the time consumed (0.66h/Mg) for transport to the collection center
Raking	-	-	0.11	
Baling	-	0.43	0.2	
Roadsiding and stacking	-	1.33	-	
Loading	2	1	0.26	
Transport	1	0.5	0.57	
unloading	2	1	0.26	
Chopping	0.66	0.66	0.66	
Baling straw chopped	0.33	0.33	0.33	0.33
total	**27.32**	**5.25**	**2.39**	**1.54**

Energy requirements

The total Energy requirements during all the stages of baling operation for three systems are summarized in Table (9) and plotted in Fig.(9) The results showed that Combine pick up and chopping straw system gave the lowest value of energy consumption of 27.02 (kW.h/Mg) , While the highest value 35.76 kW.h/Mg -was obtained in case of Round baling system. It is also clear that, Manual collecting system, rectangular baling system consumed approximate amount of energy ranged between 28.83 and 29.675 (kW.h/Mg).

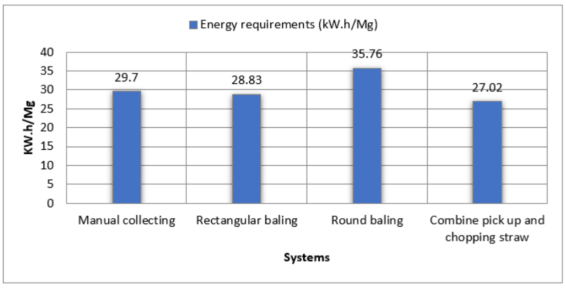


Fig. (9): Energy requirements (kW.h/Mg) for rice straw recycling systems into chopped bales.

Table (8) : Energy requirements (kW.h/Mg) for rice straw recycling systems into chopped bales.

Operation \ System		Manual collecting		Baling straw: Rectangular baling		Baling straw: Round baling		Combine pick up and chopping straw	
collecting		1.6		-		-		12.12 kW.h/Mg (Awad, et al., 2022) In addition to the energy consumed (9.48 kW.h/Mg) for transport to the collection center	
Raking		-		-		1.05			
Baling		-		5.5		3.79			
Road siding and stacking		-		0.13					
Loading		0.15		0.075		3.37			
Transport		12.65		7.907		9.03			
unloading		0.15		0.075		3.37			
Chopping	Mechanical energy	9.48	9.73	9.48	9.73	9.48	9.73		
	Human energy	0.25		0.25		0.25			
Baling straw chopped	Mechanical energy	5.27	5.42	5.27	5.42	5.27	5.42	5.27	5.42
	Human energy	0.15		0.15		0.15		0.15	
Total energy requirements		**29.7**		**28.83**		**35.76**		**27.02**	

Transporting operation requirements:

Energy and Costs requirements for transporting operation are listed in Table (9) and plotted in Fig, (10). Based on the results obtained from the experiment of comparing rice straw recycling systems, we can conclude that: manual collecting system consumed the highest energy and need more costs, while the minimum value was obtained using rectangular baling system. Combine pick up and chopping straw need more labor in comparison with round baling system.

Table (9): transport operation energy and costs requirements for the different systems.

System requirements	transporting operation requirements: Energy (kW.h/Mg)	transporting operation requirements: Costs (L.E/Mg)
Manual collecting	12.65	125
Rectangular Baling	7.9	53.5
Round Baling	9.03	71.33
Combine pick up and chopping straw	9.48	80.25

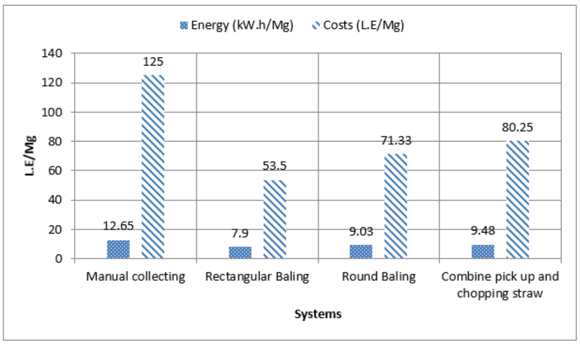


Fig. (10): Requirements transport operation for the different systems.

Density and Size requirements for storing:

The main rice straw recycling problem is its low density that increases the transportation costs from the field, need more machines and workers and much time required to recycle rice straw into chopped bales . Density and size requirements for storing the rice straw were calculated and recorded as shown in Table (10) and plotted in Fig. (12). The obtained results showed that round bales have more bulk density and Chopped rice straw bales came in the second order meanwhile rectangular bales ranks the third. The minimum size needed for storing of 16 m³/fed was obtained with chopped rice straw bales and round bales came in the second order meanwhile rectangular bales ranks the third. The data also showed that rice straw stalks without any operation needs more area to store 50 m^3.fad^{-1}**.**

Table (10): Bulk density (kg.m$^{-3)}$ and size requirements for storing (m^3.fadden^{-1})

rice straw		rice straw bales: rectangular bales		rice straw bales: round bales		Chopped rice straw bales	
Bulk density kg.m^{-3}	Size requirements for storing m^3.fad^{-1}	density kg.m^{-3}	Size requirements for storing bales m^3.fad^{-1}	density kg.m^{-3}	Size requirements for storing bales m^3.fad^{-1}	density kg.m^{-3}	Size requirements for storing bales m^3.fad^{-1}
60	54.5	133.1	24.6	219.3	17.29	204.6	16

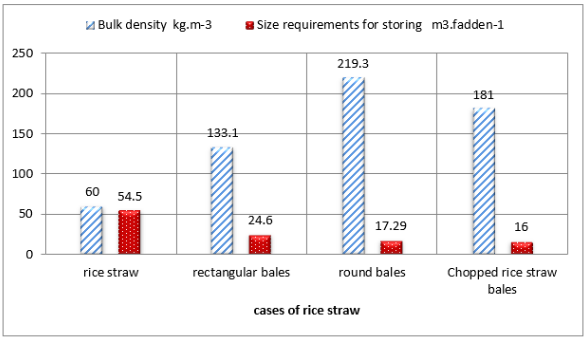


Fig. (11): Density and Size requirements for rice straw storing.

Cost Evaluation

From the economic point of view, the use of any machine usually depends on many factors like machine purchase price, labor charges and working capacity of the machine. The three systems under study were evaluated and the cost items are summarized in Table (11) and showed in Fig. (13). It is clear from the contents of total costs obtained in the previous table that the largest amount of economic cost of 910 L.E/Mg was obtained from manual collecting system compared to other systems. while the second highest system 631.8 L. E/Mg was obtained from rectangular baling followed by 601.4 L. E/Mg fore round baling system and the lowest of economic cost 517.25 L. E/Mg -was obtained from combine pick up and chopping straw system.

Table (11) Costs (L.E/Mg) for rice straw recycling systems into chopped bales.

<table>
<tr><th colspan="2" rowspan="2">System / Operation</th><th colspan="2" rowspan="2">Manual collecting</th><th colspan="4">Baling straw</th><th colspan="2" rowspan="2">Combine pick up and chopping straw</th></tr>
<tr><th colspan="2">Rectangular baling</th><th colspan="2">Round baling</th></tr>
<tr><td colspan="2">collecting</td><td colspan="2">400</td><td colspan="2">-</td><td colspan="2">-</td><td colspan="2" rowspan="9">272L.E/Mg (Awad, et al., 2022) In addition to (80.25 L.E/Mg) for cost transport to the collection center</td></tr>
<tr><td colspan="2">Raking</td><td colspan="2">-</td><td colspan="2">-</td><td colspan="2">46.6</td></tr>
<tr><td colspan="2">Baling</td><td colspan="2">-</td><td colspan="2">205.9</td><td colspan="2">92.74</td></tr>
<tr><td colspan="2">Road siding and stacking</td><td colspan="2">-</td><td colspan="2">25</td><td colspan="2">-</td></tr>
<tr><td colspan="2">Loading</td><td colspan="2">37.5</td><td colspan="2">18.75</td><td colspan="2">40</td></tr>
<tr><td colspan="2">Transport</td><td colspan="2">125</td><td colspan="2">53.5</td><td colspan="2">71.33</td></tr>
<tr><td colspan="2">unloading</td><td colspan="2">37.5</td><td colspan="2">18.75</td><td colspan="2">40</td></tr>
<tr><td rowspan="2">Chopping</td><td>Mechanical cost</td><td>83.33</td><td rowspan="2">145.8</td><td>83.33</td><td rowspan="2">145.8</td><td>83.33</td><td rowspan="2">145.8</td></tr>
<tr><td>Human</td><td>62.5</td><td>62.5</td><td>62.5</td></tr>
<tr><td rowspan="2">Baling straw chopped</td><td>Mechanical cost</td><td>127.5</td><td rowspan="2">165</td><td>127.5</td><td rowspan="2">165</td><td>127.5</td><td rowspan="2">165</td><td>127.5</td><td rowspan="2">165</td></tr>
<tr><td>Human cost</td><td>37.5</td><td>37.5</td><td>37.5</td><td>37.5</td></tr>
<tr><td colspan="2">Total costs</td><td colspan="2">910</td><td colspan="2">631.8</td><td colspan="2">601.47</td><td colspan="2">517.25</td></tr>
</table>

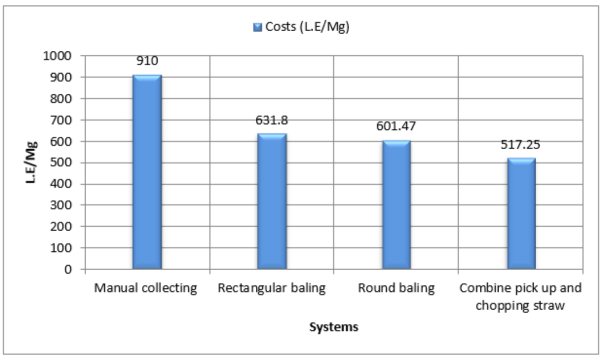


Fig. (12): Costs (L.E/Mg) for rice straw recycling systems into chopped bales.

Total Labor, time, Energy and costs requirements:

The effect of rice straw recycling systems on total Labor, time, Energy and costs requirements are showed in Table (12).

System requirements	Manual collecting	Baling straw		Combine pick up and chopping straw
		Rectangular Baling	Round Baling	
Energy requirements(kW.h/Mg)	29.7	28.83	35.76	27.02
Time requirements (h/Mg)	27.32	5.25	2.39	1.54
Human requirements (Laborer. h/Mg)	31	10	7	3
costs requirements (L.E/Mg)	910	631.8	601.47	517.25

It is clear from the contents of total energy, time, labor, and costs requirements presented in the previous table that the manual labor system was the highest in terms of cost, time consumption and the number of workers required, followed by the second and third systems.

4. Conclusions

The results concluded that, the manual labor system was the highest system in terms of cost, time consumption and the number of workers required followed by the second and third systems, respectively.

Recommendations

•It is necessary to develop these systems and reduce the number of their stages to raise the efficiency of the recycling process. and reduce its economic cost.

•The development of rice straw balers should be achieved in order to, reduce time and cost of recycling operation, improve the properties of chopped rice straw and present it in its optimal form for using.

Chopping rice straw before baling operation will also save the energy requirement and increase bale density which decrease the size requirements for storing bales.

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