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Effect of Rice Straw Picking up Method on the Performance of a Rectangular Baler

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Abstract

In Egypt, there are about 0.63 million hectares (1.5 million Feddans) cultivated area with rice each year. This results in nearly 4 million tonnes of rice straw. In this study, two methods of rice straw picking up were evaluated under field conditions using a rectangular baler. These include the mechanical picking up at three forward speeds and manual picking up at three feeding rates after harvesting with and without combine, respectively. Measurements were taken for field topography after harvesting, straw moisture content. Fuel consumption, baler productivity, bale density, baling power, and the total cost of baling were determined for the two picking up methods. Results indicated that the most favorable conditions in terms of the lowest baling power and the total cost of baling were obtained with mechanical picking up after harvesting with combine at 4 km/h forward speed. There were also significant differences between picking up methods and the baler productivity, bale density, and the fuel consumption of the baler.

Keywords: Rectangular baler, Picking up, Field topography, Baling power, Bale density.

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Introduction

In Egypt, there are about 0.63 million hectares (1.5 million Feddans) cultivated area with rice each year. This resulted in nearly 4 million tonnes of rice straw (average of 6 ton/ha). Most farmers used to burn their straw yield at the end of the rice-harvesting season. This may have been considered as the essential reason for the black cloud that shrouds Cairo at the month of October every year. Results of environmental studies (California Agriculture Magazine, 1991) indicated that one tone of rice straw burning would produce about 56 kg of carbon monoxide (CO). Therefore, if only one million tones have been burnt each year, the total amount of carbon monoxide (CO) would have reached to 56,000 tones. This indeed, will cause increased the rate of air pollution that considers the primary reason of infection by cancer disease. Therefore, overcoming the rice straw problem has stimulated scientists and the Egyptian Government in finding alternative handling methods to protect the environment by preventing air pollution and health hazards. Baling the rice straw into rectangular or round bales is the important step in handling rice straw for other applications such as animal feeding, fuel, and fiber for paper manufacturing. Thus, the main objective of this paper is to evaluate the effect of picking up method on the performance of a rectangular baler under field conditions.

Literature Review

There was a dramatic increase in the numbers of field balers for the following reasons: a) makes of more convenient manual and mechanical handling of hay, b) makes a more saleable product, and c) least space required for storing and trucking (Finner, 1973). On the other hand, the performance of these machines was affected by the following factors: 1) the condition of field surface, 2) the condition of the hay, 3) the size and uniformity of the windrows, 4) the capacity of the picking up and feed mechanisms, 5) the forward speed of the baler, and 6) the amount of power available (Kepner *et al.*, 1978).

Srivastava *et al.* (1993) mentioned that the two types of balers in popular use for baling straw and other fibrous materials are rectangular and round balers. They added that the bale density of the straw is affected by the type of material being baled, its moisture content at time of baling, and the resistance provided by convergence of the bale chamber. They also proposed the following equation to determine the baling rate of a rectangular baler as follows:

$$m_f = \frac{d_c w_c \delta_s \rho_c n_c}{60}$$

Where:

- m_f = baling rate (kg/s),
- d_c = depth of bale chamber (m),
- w_c = width of bale chamber (m),
- δ_s = thickness of each compressed hay slice (m),
- ρ_c = compressed density of hay of bale (kg/m^3), and
- n_c = crank speed (rpm).

The bale density increased by increasing baler feeding rate and the moisture content of the materials being baled (Morad, 1996). He also found that the optimum bale density was obtained by using the plunger-type field baler (36 x 46 cm bale chamber) at the feeding rates ranged from 4.2 to 6.0 ton/h. and the moisture content of rice straw bales ranged from 15 to 20%. On the other hand, the average bale density was 157 kg/m^3 by using the plunger-type field baler (41x 46 cm bale chamber) at the feeding rates ranged from 1.86 to 3.84 ton/h. and at 13% moisture

content of alfalfa straw bales (Burroughs and Graham, 1954).

The power required during baling depends upon the quantity of charge delivered per unit area, its moisture content and bale density (Klenin et al., 1985). They also derived a mathematical relationship between the power required for baling straw in relation to the specific power consumption, the weigh of windrow per meter length, and the forward speed of operation as follows:

$$N = 3.6 \times \epsilon \times q_w \times v$$

Where:

N = the power required, (kW),

ϵ = specific power consumption of straw baled in (kW.h/ton),

q_w = the weigh of windrow per meter length (kg/m), and

v = the forward speed of operation, (m/sec.).

The effect of power requirement of baling straw on the baler feeding rate have been studied by several researchers (Graham, 1953; Morad, 1996; and El-Danasory and Imbabi, 1998). They found that the power requirement increased with an increase of both the baler feeding rate and the forward speed of baler along the windrow. They also added that most of this power is used in driving the plunger. Interruption of windrow pickup during the baler operation causes a gradual reduction in baler PTO power requirements (Freeland et al., 1988). They also recommended that manufactures might wish to determine optimal windrow feeding rate for a particular baler model and provide a visual feedback signal from a feeding rate sensing device to the operator. This signal would indicate an increase or decrease in forward travel speed.

Experimental Procedure

Field experiments were carried out during the Agricultural season of 2000/2001 at the Agricultural Research and Experimental Station of the Faculty of Agriculture at Moshtohor, Zagazig University (Benha Branch), Kalyobia Province, Egypt. The field soil was a clay soil having 49% clay, 37% silt, and 24% sand. The varieties of rice were Sakha 101 (short length) for mechanical picking up and Giza 181 (long length) for manual picking up.

Two methods of picking up were used to evaluate the performance of a rectangular baler under this study. These were the mechanical picking up after harvesting with combine at three forward speeds and the manual picking up after harvesting manually at three feeding rates. The soil and stubbles heights profiles were determined for both methods of picking up before testing. All experiments were conducted using a rectangular-type (Figure 1) field baler (Model KC 747, fabricated in Egypt) with a 1.5m wide picking up and 0.36 x 0.46m bale chamber (cross-sectional dimensions). The baler was trailed using Universal tractor (800 Model, Pneumatic 2-Wheel Drive, 4-Cycle, 4-Cylinder, Direct injection, Water cooled, 77-80 HP at 1900 rpm).

The length of each run was 200 m long with the mechanical picking up and the following parameters were determined under three forward speeds. These parameters were:

- The weight of the windrow per meter length to determine the average yield of straw.
- The width of the windrow after harvesting.
- The straw moisture content was estimated using the standard methodology (ASTM, 1991).
- Fuel consumption was determined using the volumetric method.
- The weight of the windrow residual per meter length after baling.

- The baler productivity and the bale density.
- The field efficiency of the baler.
- The baling power requirement was estimated according to Embaby equation (1985).
- The total cost of baling was estimated according to ASAE (1998).

The width of the windrow after harvesting was measured three times before each run and the value ranged from 1.0 to 1.10 m. Three samples of straw for each run were collected for moisture content analysis and the value ranged from 15.3% to 20.5%.

Similar parameters were determined to evaluate the baler at the manual picking up compared with that at the mechanical picking up except for the manual picking up was carried out with young labors at three different levels of feeding rates (1.5, 1.8, and 2.2ton/h). The different feeding rates were determined according to the baler productivity, the time consumed for baling, and the straw yield.

The average values of the straw yield under this study were 7.7 and 12.6 ton/ha for the mechanical and manual pickling up methods, respectively.



Figure 1. The baler used in the field experiment.

Results and Discussion

Effect of the rice harvesting method on the field topography

Figures 2 and 3 show the cross sectional profiles of soil and stubbles heights at different methods of rice harvesting. The cross sectional profile was mapped across the direction of travel by means of a fixed horizontal ruler and a movable vertical ruler. Then, the surface roughness was calculated using Kuipers equation (1957). It was clear that, there is no difference between soil surface roughness under two methods of harvesting (Figure 2). This result may be due to the increasing of uniformity at soil surface for two methods. On the other hand, the surface roughness of stubbles heights with manual harvesting decreased by 73% than that with the combine harvesting (Figure 3). These values were 11.72% and 43.46% for manual and combined harvesting, respectively. These results may be attributed to the increasing of the stubbles heights after harvesting with combine compared with that after harvesting manually.

Baler productivity and the bale density

Figure 4 shows the baler productivity and the bale density with the speed of operation at the mechanical picking up method. The baler productivity increased with an increase in the baler forward speed. The baler productivity increased by 36%, and 54% as the baler forward speed increased from 2 to 4 km/h, and from 4 to 6 km/h, respectively. These results may be attributed to the following reasons:

- The increase in the time of baling by almost 16%, and 13% as the baler forward speed increased from 2 to 4 km/h, and from 4 to 6 km/h, respectively.
- The increase in the weight of windrow residual per meter length by almost 61%, and 26% as the baler forward speed increased from 2 to 4 km/h, and from 4 to 6 km/h, respectively.

On the other hand, the bale density decreased with an increase in the baler forward speed. The maximum value of bale density was obtained at low level of the speed of operation. However, the middle and minimum values were obtained at medium and high levels of the speed of operation, respectively. These results may have been attributed to the following reasons:

- The decrease in the baler-feeding rate as the speed of operation increased.
- The diversity of the straw being baled along the windrow and its physical properties.
- The decrease in the weight of the materials being pressed in the bale chamber at the same time unit as the speed of operation increased.

Results of the baler productivity and the bale density at the manual picking up method (Figure 5) showed similar trends with that at the mechanical picking up method except for the following differences:

- The baler productivity increased by about 25%, and 30% as the baler feeding rates increased from 1.5 to 1.8 ton/h, and from 1.8 to 2.2 ton/h, respectively.
- The time of baling increased by 29%, and 26% as the baler feeding rates increased from 1.5 to 1.8 ton/h, and from 1.8 to 2.2 ton/h, respectively.
- The bale density of baler decreased by 11%, and 18% as the baler feeding rates increased from 1.5 to 1.8 ton/h, and from 1.8 to 2.2 ton/h, respectively.

The previous results are in agreement with the previous finding by Burrough and Graham (1954), Morad (1996), and El-Danasory and Imbabi (1998).

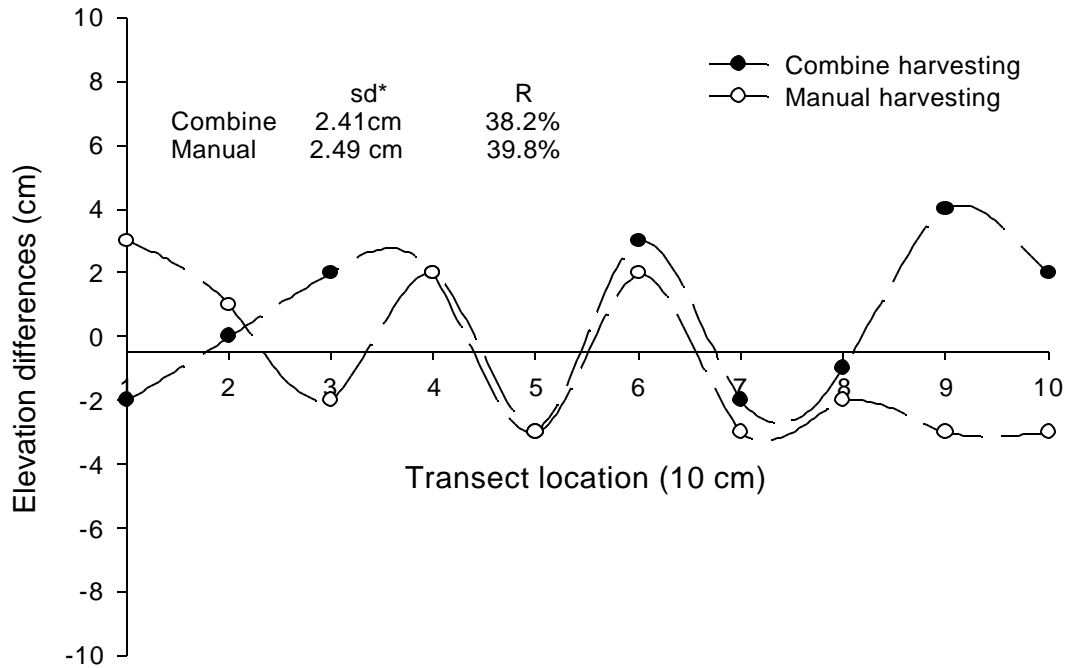


Figure 2. Soil profile after harvesting manually and with combine.

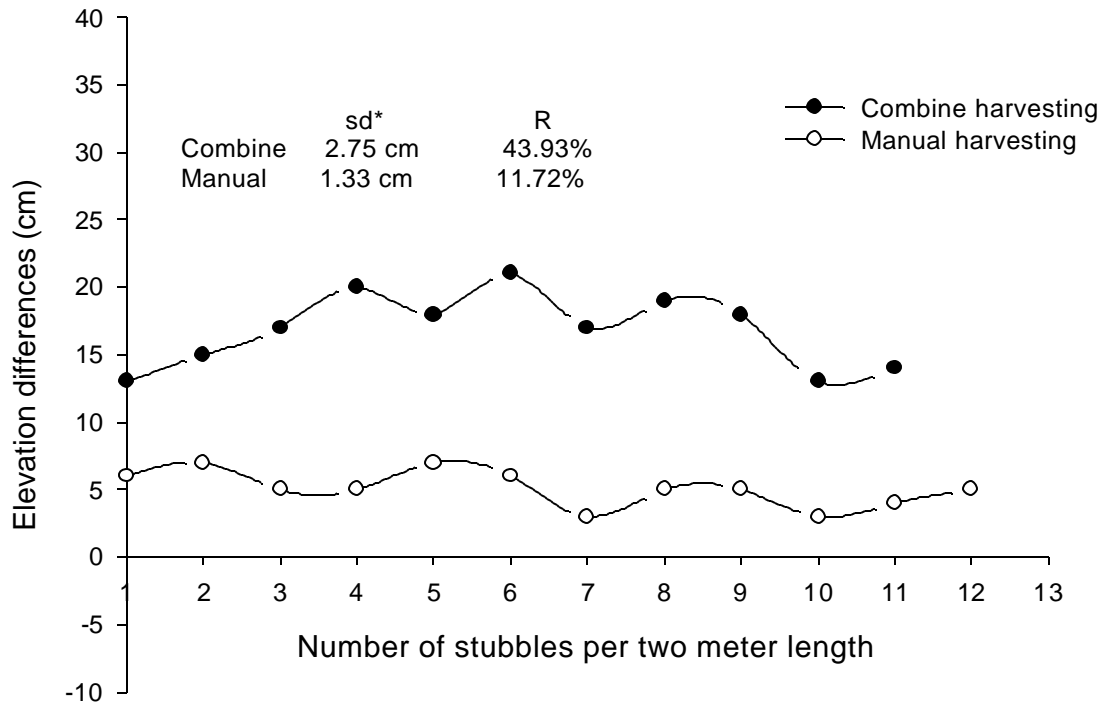


Figure 3. Stubble heights profile after harvesting manually and with combine.

* sd = standard deviation of readings (cm).

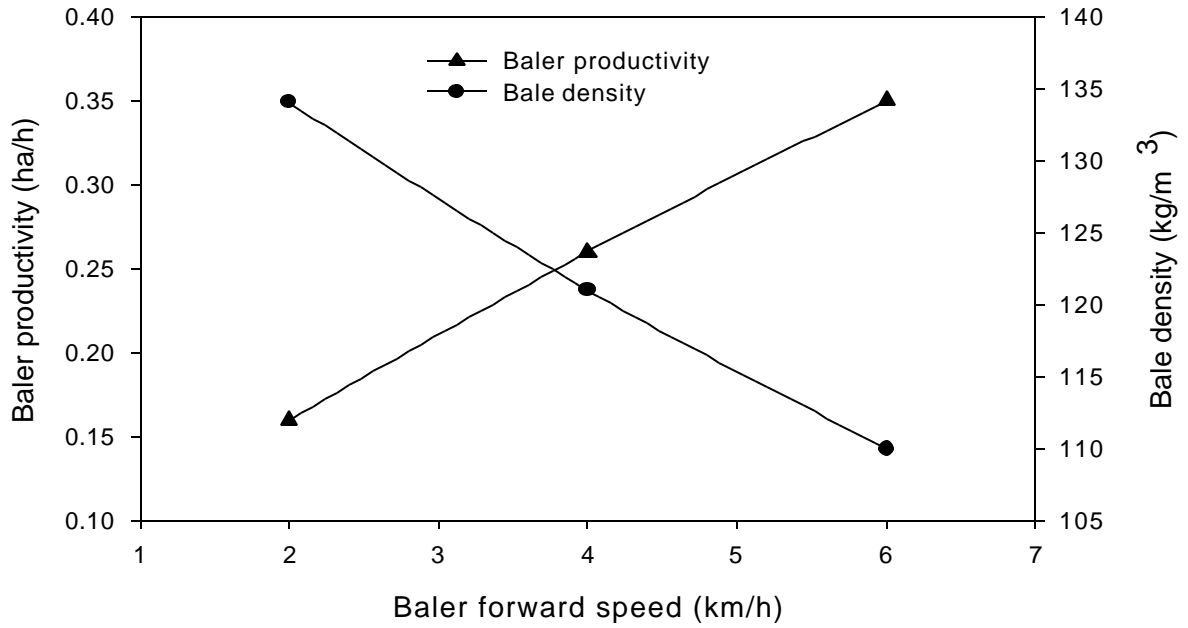


Figure 4. Effect of the baler forward speed on the baler productivity and the bale density with mechanical picking up.

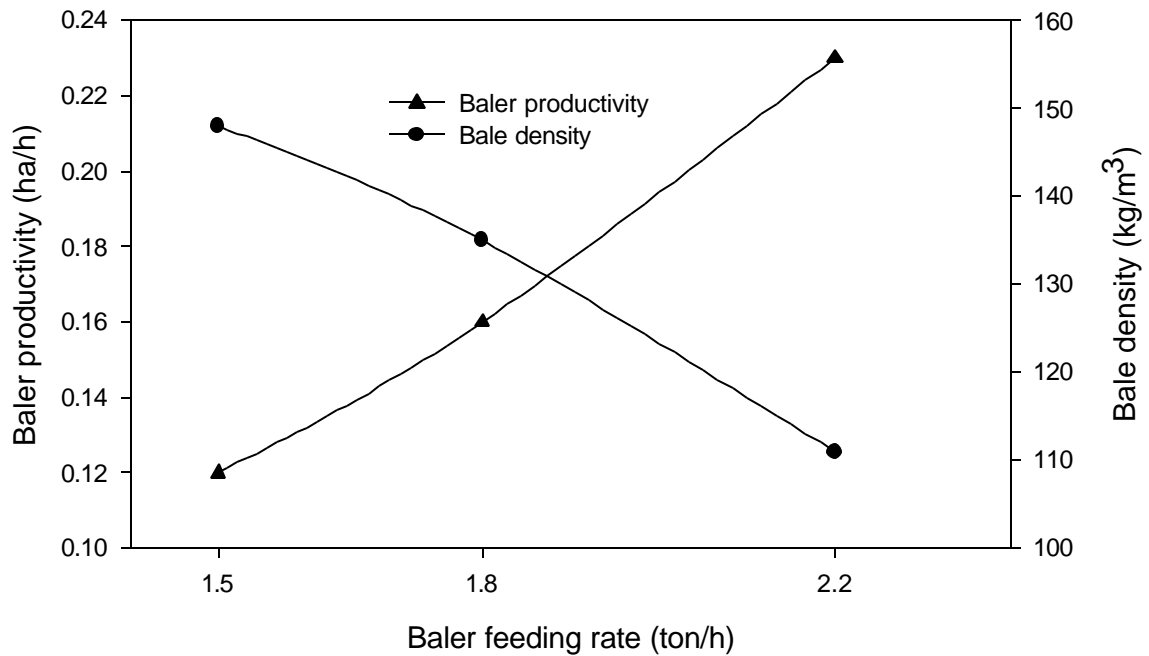


Figure 5. Effect of the baler feeding rate on the baler productivity and the bale density with manual picking up.

Baler fuel consumption and efficiency

Figure 6 shows the baler fuel consumption and the baler field efficiency with the baler forward speed at the mechanical picking up method. The baler fuel consumption increased with an increase in the baler forward speed. The increase in the speed from 2 to 4 km/h, and from 4 to 6 km/h caused increase in the baler fuel consumption by almost 12% and 15%, respectively. These results may be attributed to the increase in the baler productivity with an increase in the baler forward speed (Figure 4). Meanwhile, the baler field efficiency decreased with an increase in the baler forward speed. The maximum value of baler field efficiency was obtained at low level of the baler forward speed. However, the middle and minimum values of baler field efficiency were obtained at medium and high levels of the speed of operation respectively. These results may be due to the increase in the baler productivity (ha/h) and the time losses for balling (h/ha) as the forward speed increased.

Similar trends of the baler fuel consumption and the baler efficiency were obtained at the manual picking up method (Figure 7) compared with that at the mechanical picking up method except for the following differences:

- The baler fuel consumption increased by 39%, and 27% as the baler feeding rates increased from 1.5 to 1.8 ton/h, and from 1.8 to 2.2 ton/h, respectively.
- The average value of the fuel consumption with manual picking up at the three levels of feeding rates decreased by about 31% compared to the mechanical picking up at the three levels of the forward speed. This may have occurred due to the increasing in the rolling resistance of the wheel tractor and also the increasing in the force required for picking up, which might cause increased the fuel consumption with the mechanical picking up method.
- The baler efficiency decreased by 15%, and 22% as the baler feeding rates increased from 1.5 to 1.8 ton/h, and from 1.8 to 2.2 ton/h, respectively.
- The average value of the baler efficiency with manual picking up at the three levels of feeding rates increased by 23% compared to the mechanical picking up at the three levels of the forward speed. This result may have been attributed to the decrease in the actual width of the windrow (1.0 m wide) as a comparison with the effective width of the baler (1.5 m wide). This might cause decreased the actual field capacity of the baler with the mechanical picking up method.

Baling power requirement

Figure 8 presents the average values of the baling power requirement in (kW.h/ha) and (hp) with the manual picking up at the three levels of baler feeding rates. As expected, the baling power requirement decreased with an increase of the baler feeding rates. The highest value of the baling power requirement (98.1 kW.h/ha) was obtained at the lowest level of the baler-feeding rate (1.5 ton/h). However, the highest level of the baler-feeding rate (2.2 ton/h) resulted in the lowest value of the baling power requirement (80.4 kW.h/ha). There was no appreciable change in the baling power requirement when baler-feeding rate increased from 1.5 to 1.8 ton/h. However, the baling power requirement decreased by about 16% when the baler-feeding rates increased from 1.8 to 2.2 ton/h. These results may have been attributed to the following reasons:

- The increase in the baler fuel consumption as the baler feeding rates increased.
- The increase in the actual baler field capacity (effective productivity of baler) by 30%, and 47% as the baler feeding rates increased from 1.5 to 2.2 ton/h, respectively (Figure 5).
- The increase the material in the bale chamber, which may cause increased the load in the baler plunger.

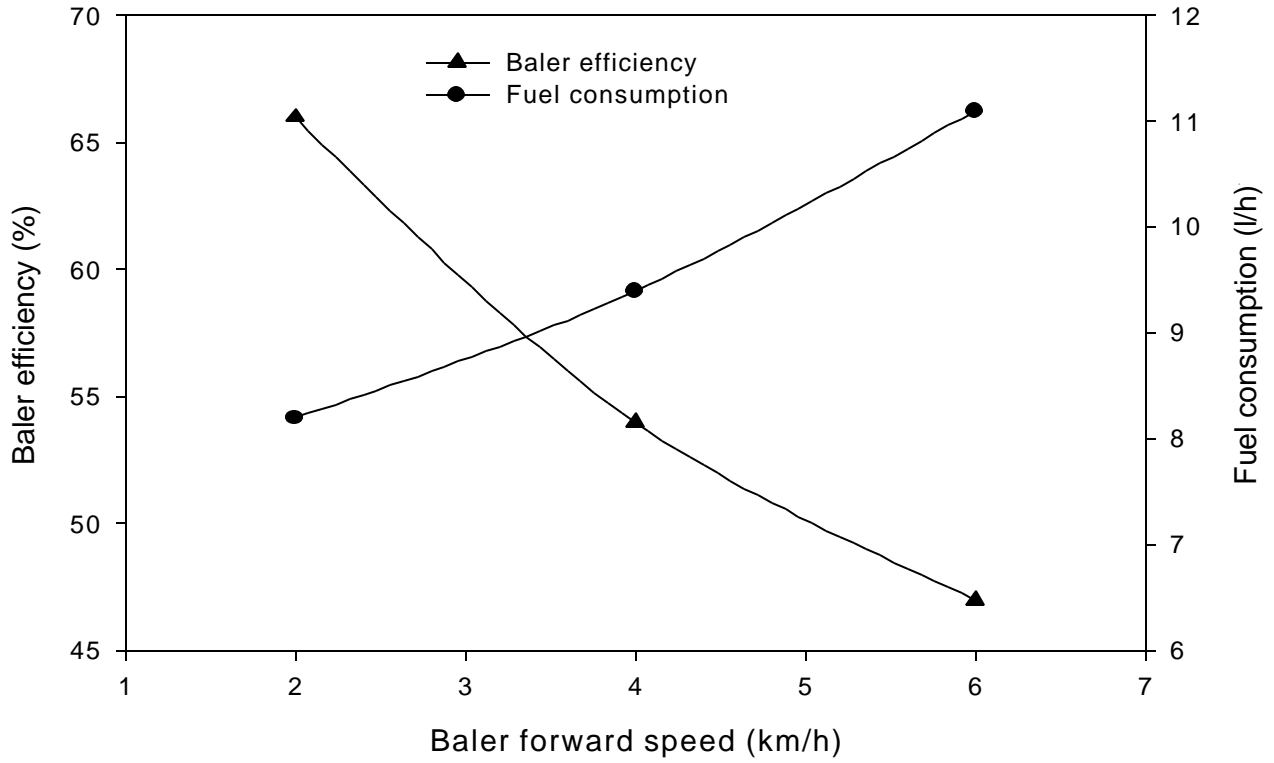


Figure 6. Effect of the baler forward speed on the fuel consumption of baler and the baler efficiency with mechanical picking up.

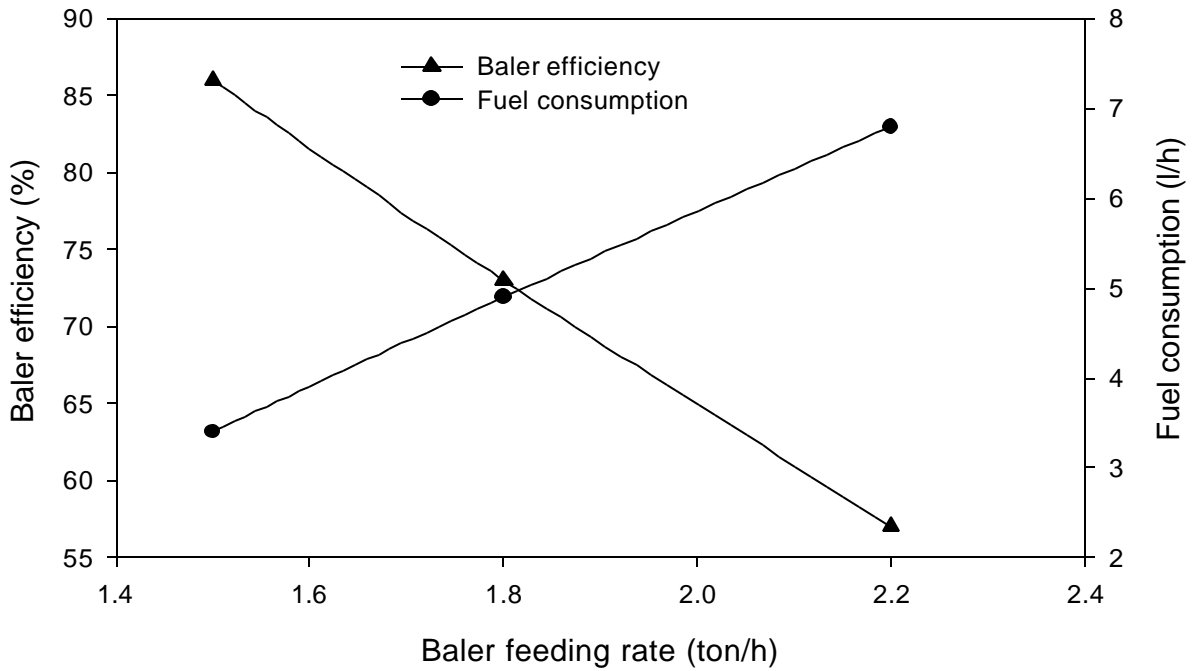


Figure 7. Effect of the baler feeding rate on the fuel consumption and the baler efficiency with manual picking up.

Similar trends of the baling power requirement were obtained with the mechanical picking up (Figure 9) compared with that at the manual picking up except for the following differences:

- The baling power requirement decreased by 28%, and 38% as the baler forward speed increased from 2 to 4 km/h, and from 2 to 6 km/h, respectively.
- There was no difference between the average value of the baling power requirement with manual picking up compared with that at the mechanical picking up.

Regression analysis was performed to derive a mathematical relation between the baling power requirement with respect to baler forward speed, baler fuel consumption, and baler feeding rate for the manual and mechanical picking up. The derived equations are:

For the manual picking up

$$P_{\text{baler}} = 152 - 39.6FR + 2.57FC \quad (R^2 = 0.95)$$

For the mechanical picking up

$$P_{\text{baler}} = -167 - 44.6v + 45.9FC \quad (R^2 = 0.99)$$

Where:

- P_{baler} = baling power requirement (kW.h/ha),
- FR = feeding rate of the baler (ton/h),
- FC = Fuel consumption of the baler (l/h), and
- v = the baler forward speed, (km/h).

Total cost of baling

Table 1 and Figure 10 show the total cost of baling in (L.E./h) and (L.E./ha) under the two methods of picking up. The total cost of baling decreased with an increase of the baler feeding rates. The highest value of the total cost of baling (682.5 L.E./ha) was obtained at the lowest level of the baler-feeding rate (1.5 ton/h). The total cost of baling decreased by about 30% when the baler-feeding rate increased from 1.8 to 2.2 ton/h. These results may have been attributed to the increase in the baler productivity by 30%, and 47% as the baler feeding rates increased from 1.5 to 2.2 ton/h, respectively (Figure 5).

Similar trends of the total cost of baling were obtained with the mechanical picking up (Figure 11) compared with that at the manual picking up except for the following differences:

- The total cost of baling decreased by 30%, and 26% as the baler forward speed increased from 2 to 4 km/h, and from 4 to 6 km/h, respectively.
- The average value of the total cost of baling with manual picking up increased by about 40% compared with that at the mechanical picking up. This may be due to the increase in the total workers required for collecting the straw and feeding the baler with manual picking up method.

Statistical analysis

Analysis of variance was conducted using the MINITAB statistical package under the two methods of picking up. Then, the least significant difference (LSD) test was estimated for the mean values of the bale density, baler productivity, baler efficiency, baler fuel consumption, power requirement of baling, and the total cost of baling in relation to baler forward speed and baler feeding rate. Results of this analysis are shown in Table 2, which confirm the previous discussion.

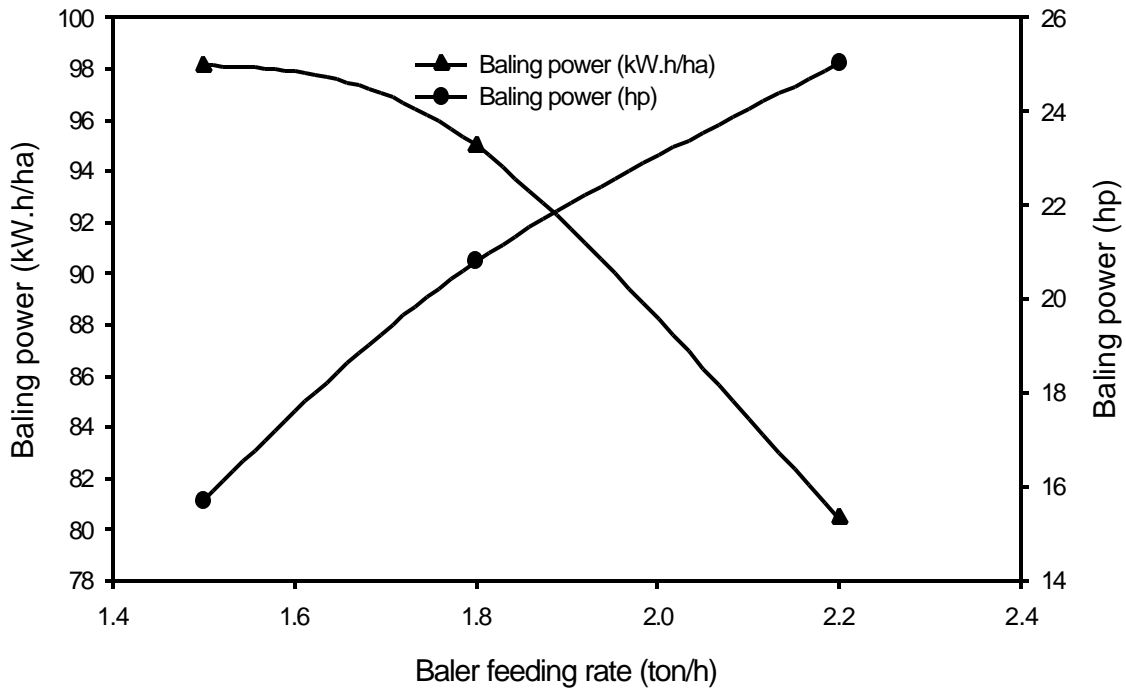


Figure 8. Effect of the baler feeding rate on the baling power requirement with manual picking up.

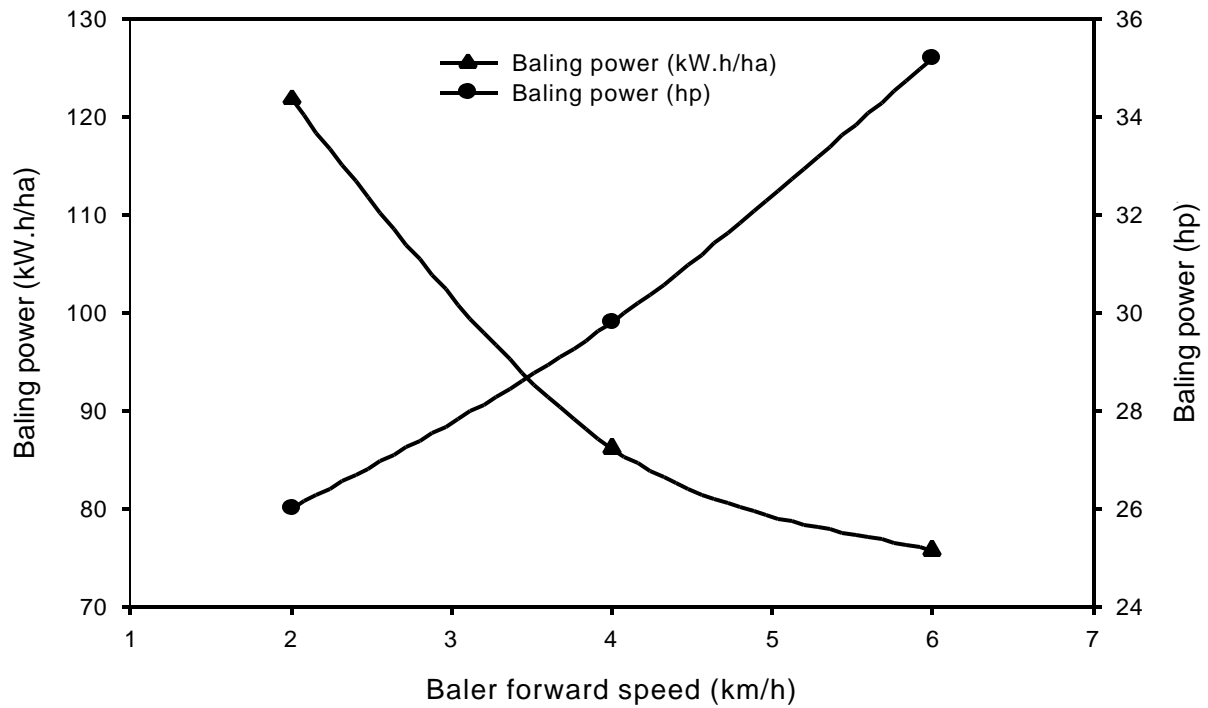


Figure 9. Effect of the baler forward speed on the baling power requirement with mechanical picking up.

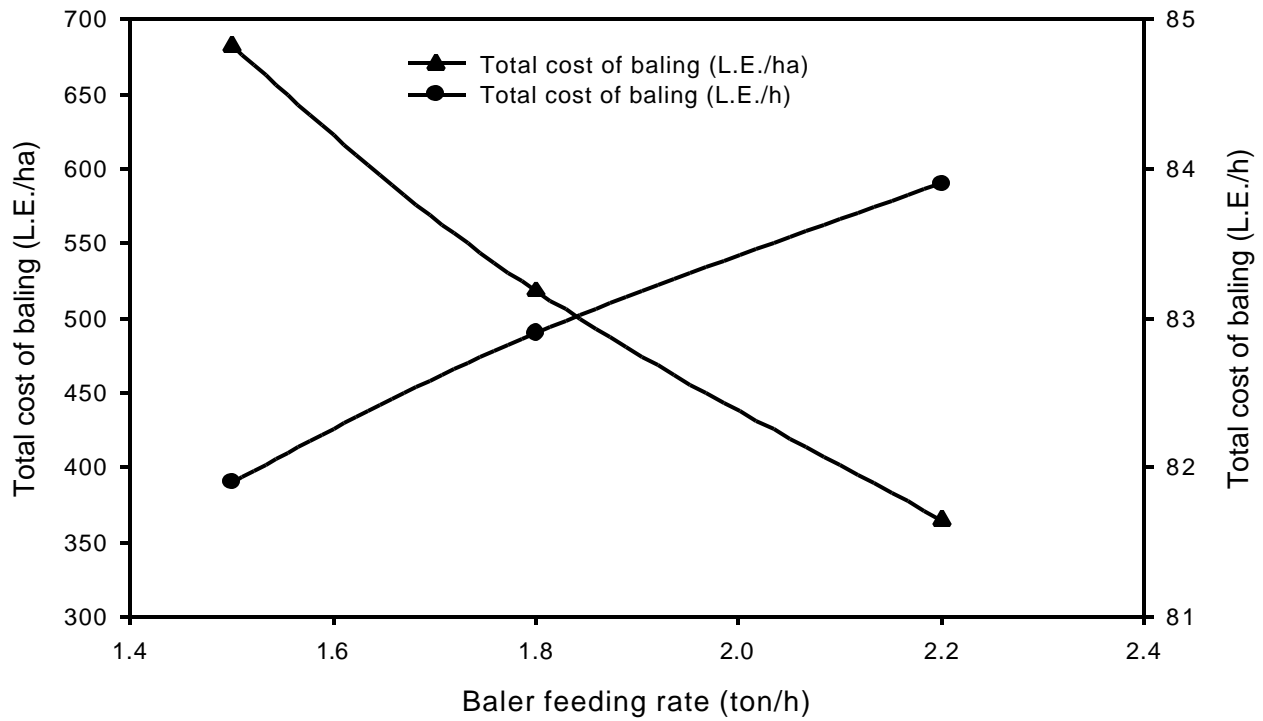


Figure 10. Effect of the baler feeding rate on the total cost of baling with manual picking up.

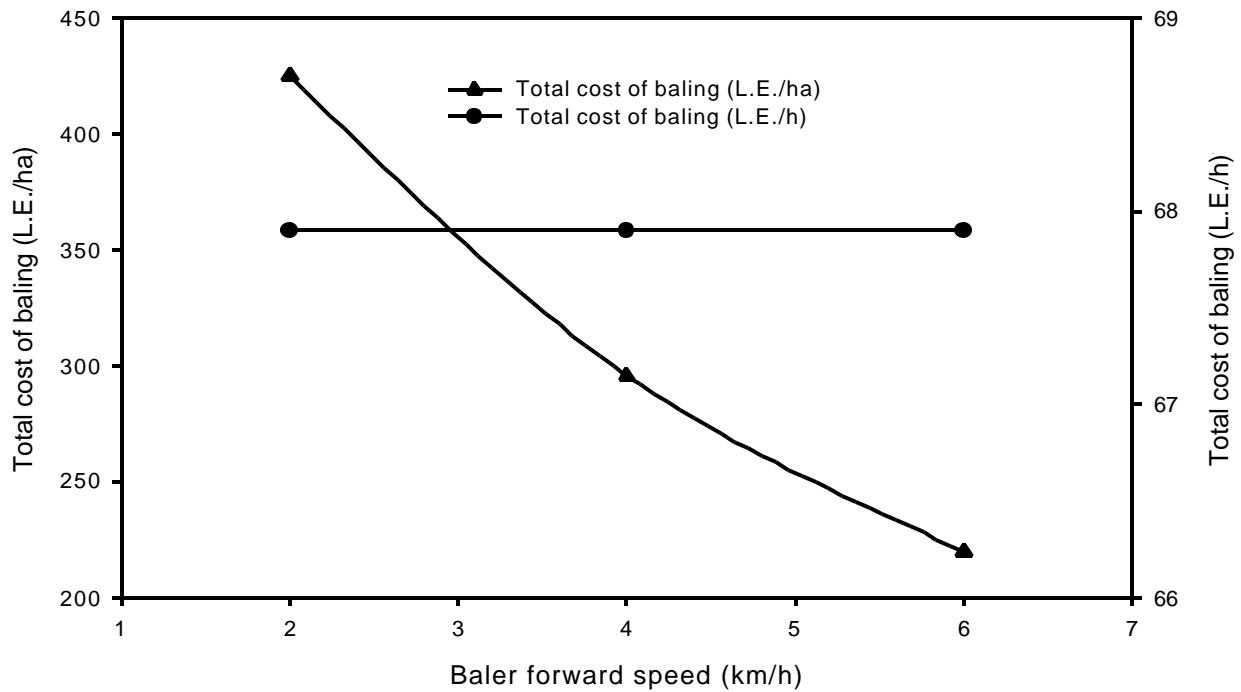


Figure 11. Effect of the baler feeding rate on the total cost of baling with mechanical picking up.

Table 1. The total cost of baling for the two methods of picking up.

Item of costs	Mechanical picking up			Manual picking up		
	Forward speed			Feeding rate		
	2 km/h	4 km/h	6 km/h	1.5 ton/h	1.8 ton/h	2.2 ton/h
Tractor cost, (L.E./h).	15.8	15.8	15.8	15.8	15.8	15.8
Price of baler, (L.E.).	36000	36000	36000	36000	36000	36000
Life hours, (h).	2000	2000	2000	2000	2000	2000
Yearly use, (h/year).	200	200	200	200	200	200
Depreciation, (L.E./h).	18	18	18	18	18	18
Interest, (L.E./h).	10.8	10.8	10.8	10.8	10.8	10.8
Taxes, insurance & shelter, (L.E./h).	5.4	5.4	5.4	5.4	5.4	5.4
Repair and maintenance, (L.E./h).	8.9	8.9	8.9	8.9	8.9	8.9
Twine, (L.E./h).	8.0	8.0	8.0	8.0	8.0	8.0
Labors, (L.E./h).	1.0	1.0	1.0	15	16	17
Actual field capacity, (ha/h).	0.16	0.26	0.35	0.12	0.16	0.23
Total cost, (L.E./h).	67.9	67.9	67.9	81.9	82.9	83.9
Total cost, (L.E./ha).	424.4	295.7	219.7	682.5	518.1	364.8

Table 2. The least significant difference (LSD) for the mean values of baler productivity, bale density, baler efficiency, baler fuel consumption, baling power, and the total cost of baling for the two methods of picking up.

Variable	Mechanical picking up			Manual picking up		
	Speed (km/h)	Mean*	LSD(0.05)	Feed rate (ton/h)	Mean*	LSD(0.05)
Productivity of baler (ha/h)	2	0.16 ^a	1.55	2	0.12 ^a	0.74
	4	0.26 ^a		4	0.16 ^a	
	6	0.35 ^a		6	0.23 ^a	
Bale density (kg/m ³)	2	134 ^a	8.4	2	149 ^a	13.81
	4	121 ^b		4	135 ^b	
	6	110 ^c		6	111 ^c	
Baler efficiency (%)	2	66 ^a	1.57	2	86 ^a	0.75
	4	54 ^a		4	73 ^a	
	6	47 ^a		6	57 ^a	
Baler fuel consumption (l/h)	2	8.2 ^b	1.99	2	3.4 ^c	1.42
	4	9.4 ^{ab}		4	4.9 ^b	
	6	11.1 ^a		6	6.8 ^a	
Baling power (KW.h/ha)	2	121.8 ^a	16.52	2	99.13 ^a	6.72
	4	86.15 ^b		4	95.0 ^a	
	6	75.7 ^b		6	80.4 ^b	
Baling cost (L.E./ha)	2	424.9 ^a	72.96	2	682.5 ^a	111.02
	4	295.7 ^b		4	518.1 ^b	
	6	219.7 ^c		6	364.8 ^c	

* Means within the same column followed by the same letter are none significant.

Summary and Conclusion

Results of this study could be summarized as follows:

- With the manual picking up, the highest values of the baler productivity and the baler fuel consumption were obtained at 2.2 ton/h baler feeding rate. On the other hand, the lowest level of the baler-feeding rate (1.5 ton/h) resulted in the highest values of the bale density, baling power, baler efficiency, and the total cost of baling.

- With the mechanical picking up, the highest values of the baler productivity and the baler fuel consumption were obtained at 6 km/h forward speed of the baler. However, the highest values of the bale density, baling power, baler efficiency, and the total cost of baling were obtained at 2 km/h forward speed of the baler.
- The baler productivity with the mechanical picking up was increased by about 34% compared with that at the manual picking up. On the other hand, the baler efficiency with the manual picking up increased by 22% than that with the mechanical picking up.
- There were no appreciable changes in the baling power and the bale density for the two methods of picking up.
- The baler fuel consumption with the mechanical picking up increased by 47% than that with the manual picking up. On the other hand, the manual picking up resulted in the highest values of the total cost of baling compared with the mechanical picking up.
- Results of statistical analysis for the two methods of picking up indicated that the 4 km/h baler forward speed is the best speed could be recommended with the mechanical picking up. On the other hand, the 2.2 ton/h baler feeding rate may be considered as the better feeding rate with the manual picking up under the certain condition of this study.

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