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MECHANICAL RAKING OF HAY UNDER LOCAL CONDITIONS

R.M., Kholief,*; R.R. Abou-Shieshaa*; I. S. Yousef*

ABSTRACT

Field experiments were conducted at Sakha Agricultural Research Center, Kafr El-Sheikh Governorate, during winter season of 1999/2000 by using berseem clover (Sakha 3). The present study was carried out using two different types of raking machines. The effect of forward and rotational speeds and hay moisture content on crude protein retention, mechanical losses and energy requirements were studied. It is conceivable that quality reduction due to raking was primarily in crude protein retention; however, the increment in forward and rotational speed decreases the crude protein retention percentage.

The maximum value of crude protein retention was obtained 91.84% at forward speed of 4.05 km/h, rotational speed of 505 r.p.m. and hay moisture content of 46.18 % for rotary tedder. Whilst, the minimum value of crude protein content was 58.30 % at forward and rotational speeds of 9.61km/h and 790 r.p.m., respectively and hay moisture content of 23.67% for gyro rake machine. It is clear that the maximum value of mechanical losses 2.91% were occurred at forward and rotational speeds of about 9.61 km/h and 790 r.p.m., respectively with hay moisture content of 23.67 % for gyro rake. On the other hand, energy requirements reached 7.537 kW.h/fed at forward and rotational speeds of 4.05 km//h and 505 r. p.m., respectively with hay moisture content of 46.18% for rotary tedder machine. The cost analysis indicated that the manual cost of berseem raking is about 3.1 and 3.3 times of rotary and gyro rake machines costs.

INTRODUCTION

In Egypt berseem (Trifolium alexandrinum) is the main source of plant protein animal feeding. It's used in fresh form during winter and spring seasons from November to May every year. During the period from June to October, most of the Egyptian farmers feed their livestock on poor quality roughage's such as rice and wheat straw. Few farmers care to keep some of berseem crop in the form of hay to feed their livestock in summer.

The leaves of hay dry more rapidly than the stems, by the time, the stems have reached a moisture level sufficient for storage, and the leaves have been over dried. This excessive drying of the leaves only serves to increase shattering losses in subsequent operations.

A rake is used in haymaking to form special windrows that are important part of field curing. The properly make windrow has the small-stemmed, quick-

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drying, leafy portions of the plant surrounded by the coarse-stemmed, slow-drying part of the plant. This arrangement encourages uniform drying of the hay crop.

Rakes are also used in gathering materials together for later operations. The form of the windrow is not important for an operation as raking straw for baling. For leafy plants such as alfalfa and clovers, raking should be completed before the moisture content of the whole plant drops below 40%, the approximate point where leaf shatter occurs ***(Hunt ,1983)***.

The amount of leaf loss caused by a rake is influenced by such factors as the distance the hay is moved from the swath into the windrow, the average hay velocity the type of hay-moving action (Rolling, lifting, dragging) and any accelerating and decelerating action or periodic impacts of the rake teeth upon the hay as it is being moved. The major factor affecting the average hay velocity is forward speed. High forward speeds increase leaf shatter.

Hunt (1983) mentioned that rakes are made in three general forms as follows:

a)The conventional side-delivery rake uses an angled, spring-toothed beater to sweep the hay into a windrow. This type is normally four barred, four wheeled and ground wheel driven. A special bar positioning device is needed to keep the bar teeth brushing the material instead of picking it up.

b) Rake is the finger wheel rake which consists of several large, spring-toothed wheels in contact with the ground surface and arranged in echelon. As the rake is moved forward the wheels turn dragging the hay to one side and forming a windrow.

c) The dump rake is used in dry areas where hay is staked in the field. Dump rakes have very high capacities. The wheel rake is sometimes front mounted. Other type of rakes may be trailed, semi-mounted, or completely mounted. Rakes are driven from ground drive wheels or by a PTO shaft.

Kepner et al. (1982) stated that the indicators to be considered in evaluating or comparing rake performances are the following:

a)Amount of leaf loss due to shattering.
b)Amount of hay missed.
c)Amount of trash, dirt, stones, and other debris put into the windrows.
d)Uniformity and continuity of windrow.
e)Leafy portions should be in the center of the windrow and the stems toward the outside.

Leaf loss is one of the most important considerations, particularly if the hay is a little too dry when raked. Shattering of seed crops such as beans or alfalfa would represent a similar type of loss.

Gihad (1963) found that on dry matter basis, the crude protein and ash content decreased in berseem with the successive cuts, while the crude fiber increased.

Dobie et al. (1963) stated that drying treatments were at moisture levels of 10 to 15% which were very conducive to leaf shatter. The rake dry treatments resulted in approximately 25% less hay with nearly a 30% reduction in harvested nutrient value. Quality of the lost material measured in terms of crude protein (CP), crude fiber, and total digestible nutrients was higher than the quality of the hay in the windrow.

Harvesting of a high quality alfalfa crop is heavily dependent upon weather conditions. Under typical conditions, respiration and mechanical losses amount to a dry matter loss of 15 to 22% during the field drying of alfalfa ***(Moser, 1980).***

Savoie et al. (1982) mentioned that dry matter losses ranged from 10 to 50 kg/ha for mowing, 20 to 30 kg/ha for late conditioning and 50 to 80 kg/ha for raking. Average yields of alfalfa dry matter were 4900 and 2350 kg/ha for the first and second alfalfa cuts, respectively. Relative losses during the second cut were at least double those of the first cut.

Forage losses were due to over maturity, respiration leaching and other rain factors, mechanical handling, storage, and feeding ***(Koegel et al., 1985).*** The mechanical losses account for nearly one third of the total loss value of the three most common forage harvesting machines (rake, baler, and forage harvester), the losses caused by rakes result in the largest economic loss ***(Buckmaster et al., 1990)***

Rotz and Abrams (1988) stated that raking loss veries from 1 to 11% with raking loss inversely related to yield raised to the 2.42 power; moisture content and raking speed were held relatively constant at 35 to 45% and 5.1 km/h, respectively. Crude protein (CP) of this raking loss (20.6%) was significantly higher than CP of both the standing crop (17.7%) and CP of the hay as baled (19.0%). The neutral detergent fiber (NDF) of the raking loss (40.5%) had a higher quality than the NDFof harvested material (45.4%).

Kholief (1989) reported that the total mechanical losses of berseem clover by using mower conditioner reached 10.19% and 14.17% for mowing and baling, respectively during the second cut. Raking, tedding and baling losses are related to operating speed and the moisture content of the crop during the time of operation.

Buckmaster (1993) mentioned that dry matter retention averaged 90% and was affected by moisture content, rake type and yield. Quality reduction due to raking was primarily in crude protein; however, slight increase in fiber concentrations were observed. Retention ratios for crude protein, acid detergent fiber and neutral detergent fiber averaged 90.3, 92.3, and 93.6%, respectively.

Experiments were conducted to asses the ability of raking machine to create the land free from residues, besides reducing the exposure time and field losses of berseem clover between mowing and baling operation. The objectives were to measure raking losses, energy requirements, dry matter and crude protein retention as affected by two various types of raking machine and some different operating conditions.

MATERIALS AND METHODS

Field experiments were conducted at Sakha Agricultural Research Center, Kafr- EL-Sheikh, Governorate during winter season of 1999/2000 in an area of about 3 feddans by using berseem clover (Trifolium alexandrinum).

Shaka 3 variety during third cut. Two various types of rakes were used in the present study namely: Danish rotary tedder (CR 400) and Japanese gyro rake (GR 350). Both rotaries tedder and gyro rake were used to placing two swaths into one. Figures 1 and 2 show general view of the above mentioned machines. Table 1 summarizes the technical specifications of both two machines. A two WD tractor (Model Ford 6610) was used for operating the two machines. The tractor power had 55.97 kW (75 hp), 4 cylinders diesel engine.

The fuel consumption during the raking operation was estimated by using a fuel consumption apparatus, its capacity was about 750 ml, and it has a reading ruler divided into 15 divisions, each division reading 50 ml.

Table 1: Some technical specifications of rotary tedder and gyro rake.

Item	Rotary tedder	Gyro rake
Model	CR 400	GR 350
Working width ,m	4.00	3.90
Working speed ,km/h	Up to 15	Up to 15
Power consumption, Max. ,kW	25-30	30-60
Rake tines number	2x8	1x8
Net mass ,kg	450	390

Miscellaneous equipment:

a) Wooden frame and canvas sheet;
a) Stop watches;
b) Sighting poles;
c) Measuring tape (30 m long);
d) Balance (accuracy of 0.01 g);
e) Electric oven;
f) Balance with a maximum reading of 50 kg and accuracy of 0.5 kg.

Measuring technique:

This work was to compare raking losses, power and energy requirements and raking cost for two different raking machines. Measurements included quality reduction in terms of crude protein retention.

a) Mechanical losses :

A canvas sheet was placed under the swath to estimate the raking losses. Initial moisture content was estimated by taking small samples of about 25 g (wet mass) immediately after raking

b) Crude protein retention (CP):

Dry forage samples were taken from each plot to determine the total nitrogen content by Microkjeldhl method. The crude protein was calculated as multiplying the total nitrogen by a constant factor of 6.25 according to ***A.O.A.C. (1984)***. Retention of (CP) is the amount of (CP) in the windrow after raking divided by the amount in the swath before raking.

c) Moisture content (M):

Samples were dried at 105°C until having constant mass to calculate the moisture content. It was calculated on wet basis according to the following equation:

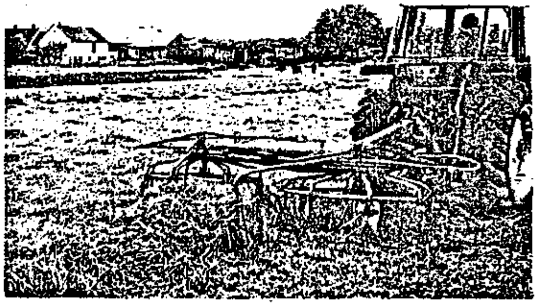

Fig. 1: Rotary tedder.

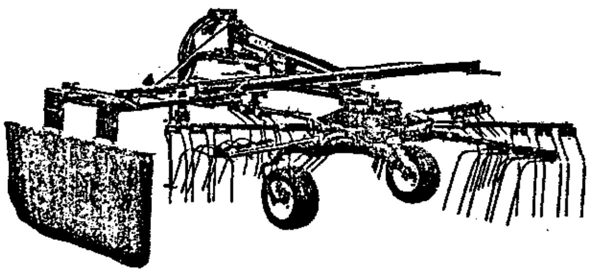

Fig. 2: Gyro rake.

$$\text{Moisture content} = \frac{\text{Mass of wet sample} - \text{Mass of dry sample}}{\text{Mass of wet sample}} \times 100, \% \quad ......1$$

d) Power consumption:

The following formula was used to estimate power consumption during the raking operation according to **Embaby (1985):**

$$EP = \left[F_C \times \frac{1}{60 \times 60}\right] \rho_f \times L.C.V. \times 427 \times \eta_{th} \times \eta_m \times \frac{1}{75} \times \frac{1}{1.36}, \text{ kW} \quad ....2$$

Where:

EP = Power requirements, kW;

F_c = Fuel consumption, l/h;

ρf = Density of the fuel, 0.85 kg/l;

$L.C.V.$ = Lower calorific value of fuel 10000 k cal/kg;

427 = Thermo-mechanical equivalent, kg.m/k cal;

η_{th} = Thermal efficiency of engine, 40 % and

η_m = Mechanical efficiency of engine, 80 %.

e) Energy requirement:

Energy required for operating of the raking machine was calculated according to the following equation: -

$$\text{Energy requirements} = \frac{\text{Power requirement } (kW)}{\text{Rate of work } (fed/h)}, \text{ kW.h/fed.}^2 \quad ....3$$

The treatments were arranged in split plot design with three replications for each machine. The treatments of hay moisture content of 46.18, 35.41 and 23.67% were arranged at random in main plots while, different rotational speeds of 505, 640 and 970 r.p.m. were assigned at random in sub-plots. Forward speeds of machine of 2.3, 4.05, 5.14 and 6.92 km/h were assigned at random in sub-sub plots.

f) Raking cost:

Cost of raking operation per unit time (C), L.E/fed. was calculated by using the following formula ***(El-Awady 1978):***

$$C = \frac{P}{h}\left(\frac{1}{l} + \frac{i}{2} + t + r\right) + (0.9w \times f \times u) + b, \text{ L.E./h} \quad ....4$$

Where:

p = estimation price of machine, L.E[3].;

h = estimation yearly hours of operation, h;
l = life expectancy of the machine in years;
i = annual interest rate, %;
t = annual taxes and overheads, %;

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[2]One feddan (fed.) = 4200.83m^2.

[3]One American dollar = 4 Egyptian Pound (L.E.) according to prices of 2001.

0.9 = a correction factor for rated load ratio and lubrication;
w = engine power, hp;
f = specific fuel consumption, l/hp.h;
u = fuel price, L.E./l and
b = hourly labour wage, L.E./h.

RESULTS AND DISCUSSION

a- Mechanical losses:

During the second berseem cut, mechanical losses were measured immediately after raking for rotary tedder and gyro rake. Figures 3 and 4 show the effect of hay moisture content, forward and rotational speeds on mechanical losses. It is conceivable that mechanical losses were confounded by the above mentioned three factors. It is notice that the increasing in forward and rotational speeds increased the mechanical losses. In the same manner, the decreasing in hay moisture content increased the mechanical losses for both two tested machines. In general, rotary tedder gave the lowest values of mechanical losses and this is may be due to maintenance of a constant height above the ground by a gauge wheel to allow some surface height variations. The highest value of mechanical loss reached 2.91% was at forward speed of 9.61 km/h, rotational speed of 790 r.p. m. and hay moisture content of 23.67 for gyro rake. Meanwhile, the lowest value was 0.57% at forward speed of 4.05 km/h, rotational speed of 505 r.p.m. and hay moisture content of 46.18% for rotary tedder.

b- Crude protein retention:

Figures 5 and 6 illustrate the effect of hay moisture content, forward and rotational speed on crude protein retention. It is clear that the increasing in forward and rotational speeds decreased the crude protein retention. This is due to the greater loss of leaves than that of the stems during raking.

However, crude protein increased by decreasing hay moisture content. Also, rotary tedder was considered superior comparing with gyro rake for crude protein retention. The maximum value of crude protein retention was 91.84% at forward speed of 4.05 km/h, rotational speed of 505 r.p.m and hay moisture content of 46.18% for rotary tedder. In the same manner, the minimum value of crude protein retention was 58.30% at forward speed of 9.61km/h, rotational speed of 790 r.p.m and hay moisture content of 23.67% for gyro rake machine.

c- Energy requirement and raking cost:

The power consumption increased substantially as the forward and rotational speeds increased. In the same manner, the decrement in hay moisture content decreased the power consumption and the unit energy. Figures 7 and 8 illustrated the relation of energy versus forward speed at various levels of hay moisture content and rotational speed for both rotary tedder and gyro rake. It can be mentioned that, the increment in forward speed from 4.05 to 9.61km/h decreased the unit energy from 7.163 to 5.02, 7.537 to 5.207 and 7.866 to 5.659 at rotational speed of 505, 640 and 790 r.p.m, respectively, for rotary tedder. However, it decreased from 7.49 to 5.049, 7.74

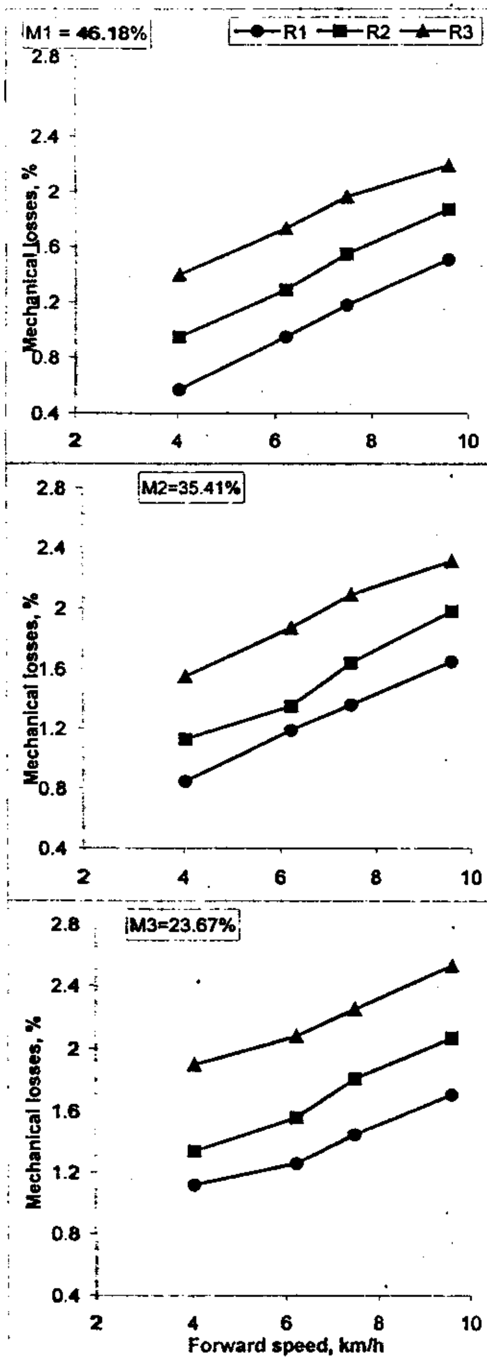

Fig. 3: Effect of forward speed, hay moisture content (M)and rotational speed (R) on mechanical losses for rotary tedder.

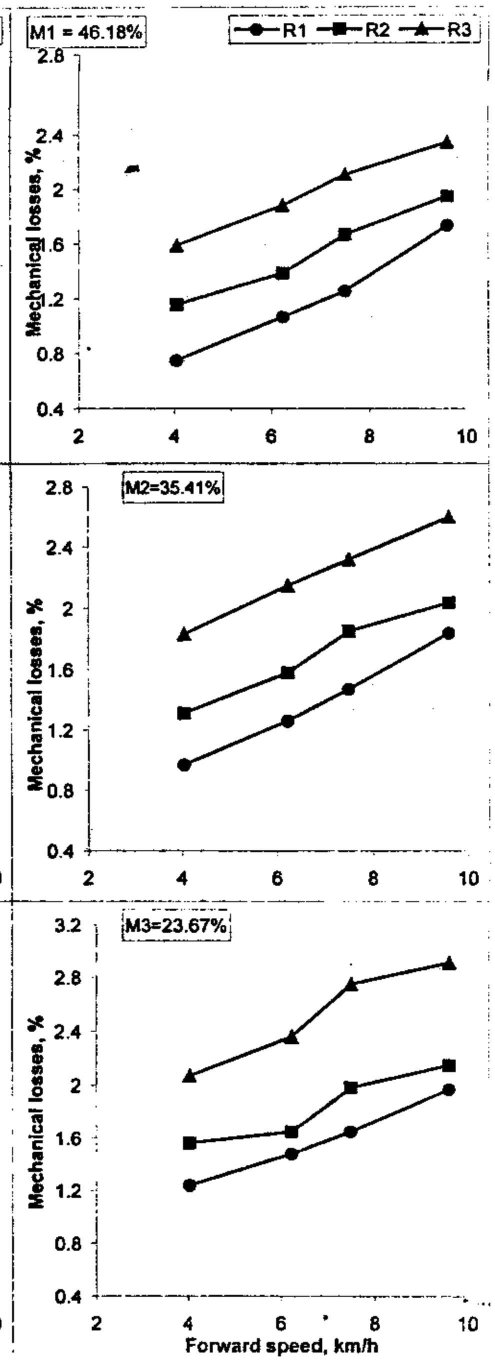

Fig. 4: Effect of forward speed, hay moisture content (M) and rotational speed (R)on mechanical losses for gyro rake.

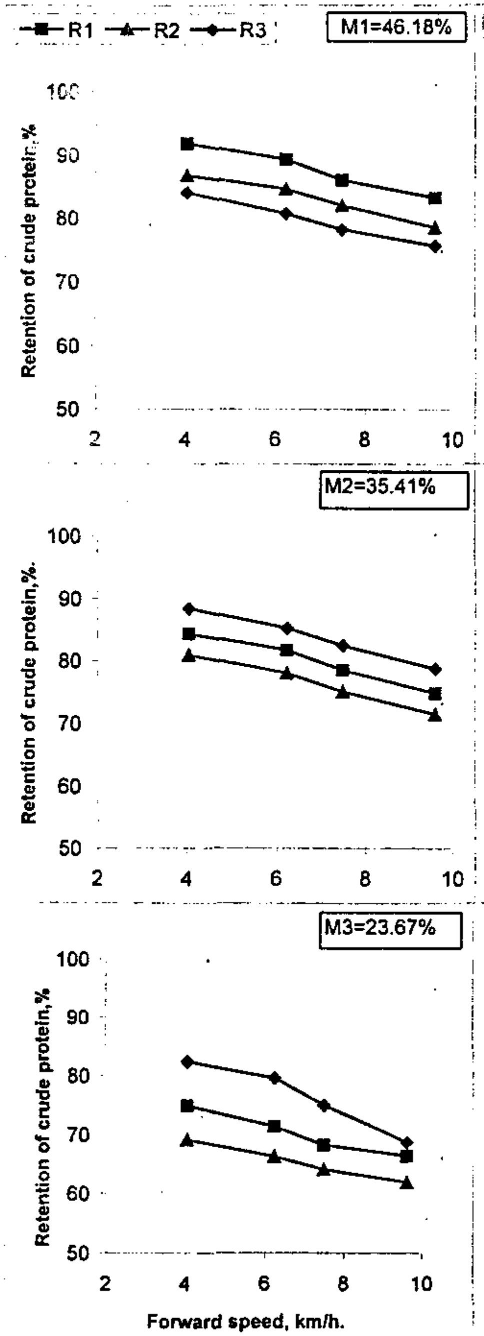

Fig. 5: Effect of forward speed, hay moisture content (M) and rotational speed (R) on retenion of crude protein for rotary tedder.

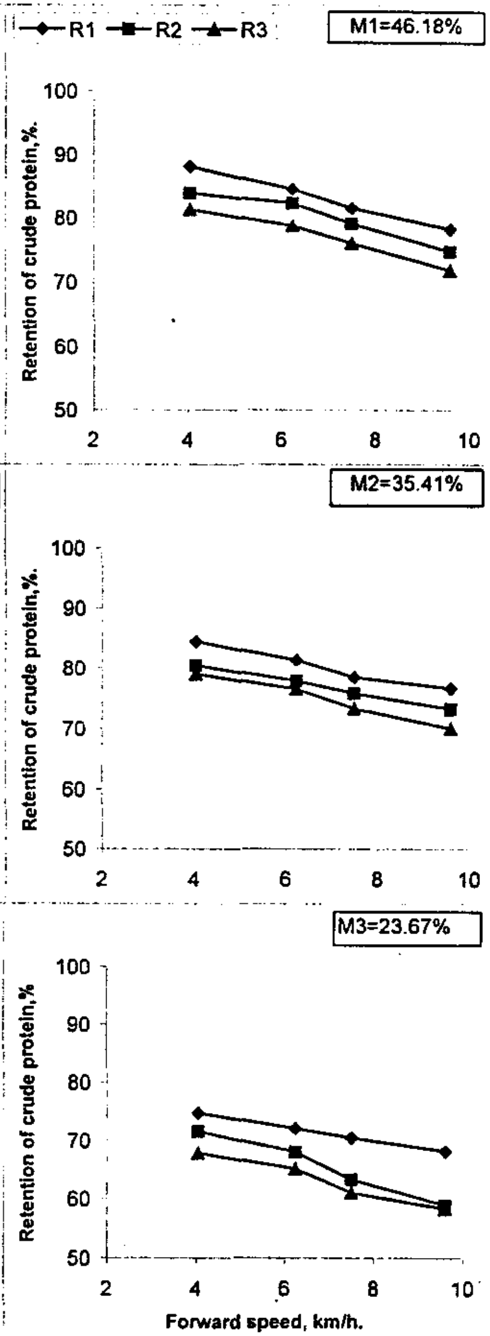

Fig. 6: Effect of forward speed, hay moisture content (M) and rotational speed (R) on retenion of crude protein for gyro rake.

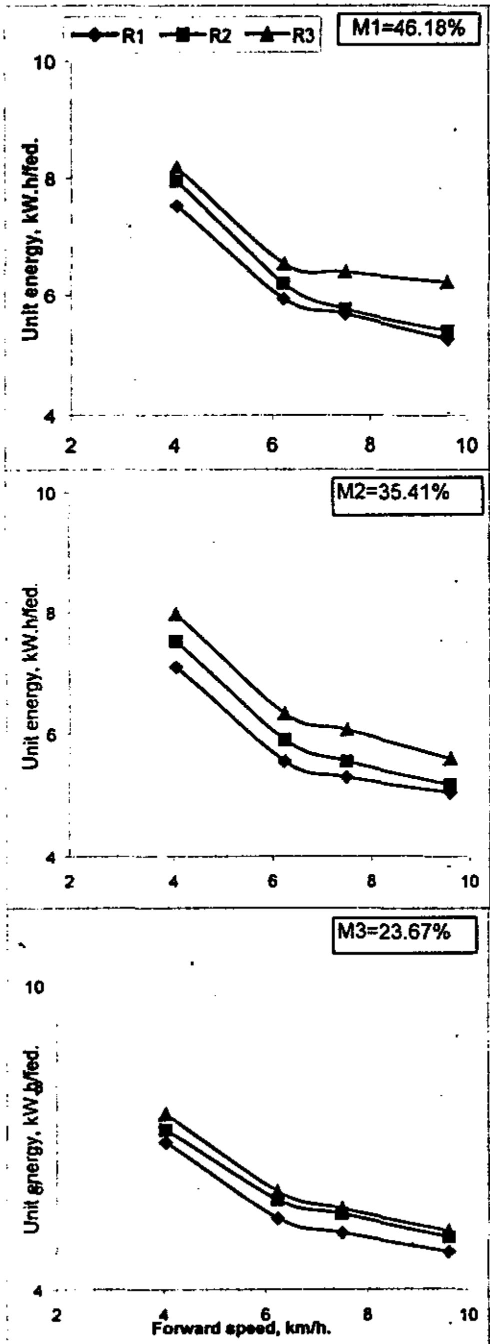

Fig. 7: Effect of forward speed, hay moisture content (M) and rotational speed (R) on unit energy for rotary tedder.

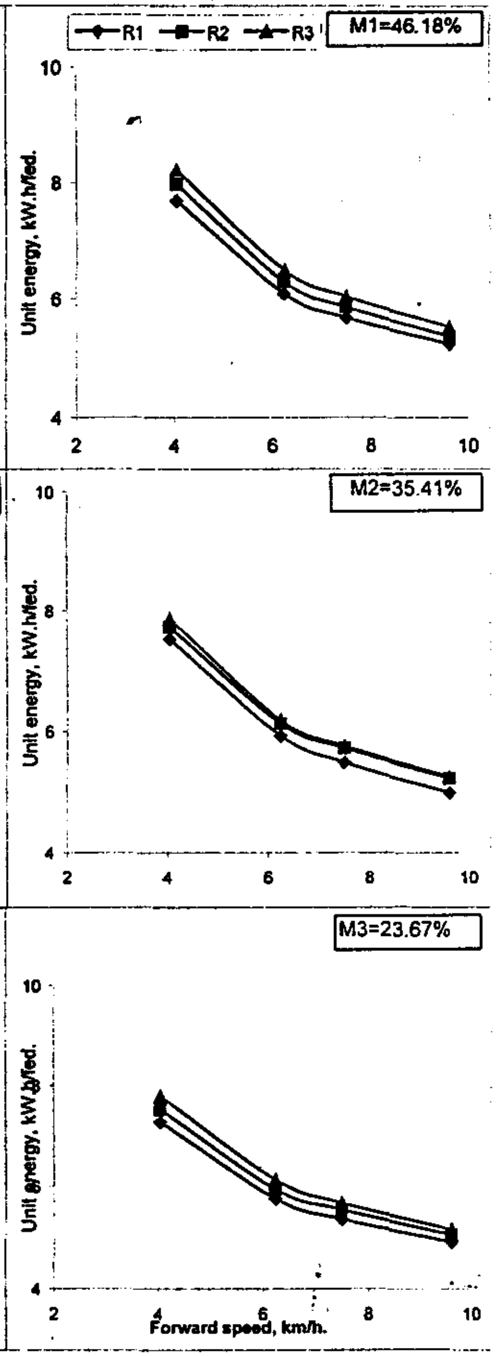

Fig. 8: Effect of forward speed, hay moisture content (M) and rotational speed (R) on unit energy for gyro rake.

to 5.21 and 7.956 to 5.31 at the same above mentioned rotational speeds for gyro rake. From the cost point of view, it can be mentioned that raking cost were decreased by increasing the forward speed.The results indicated in Table 2 shows that the forward speed increase from 4.05 to 9.61 km/h tends to increase the effective field capacity from 1.92 to 3.12 and 1.71 to 2.76 fed/h for rotary and gyro rake ,respectively. However, rotary tedder gave the lowest values of total cost in comparison with gyro rake and manual raking. Also, mechanical racking resulted a drastic reduction of 68% for total cost in comparison with manual raking.

Table 2: Effect of raking systems on fuel consumption, power requirements, and unit energy and raking cost.

Raking systems	Forward speed, km/h	Eff. field capacity, fed/h	Fuel cons., l/h	Power requir., kW	Unit energy, kW.h/fed	Raking cost	
						L.E/h	L.E/fed
Rotary tedder	4.05	1.92	4.50	14.440	7.520	12.10	6.30
	6.24	2.51	4.62	14.825	5.906	12.14	4.84
	7.50	2.76	4.78	15.339	5.557	12.20	4.42
	9.61	3.12	5.04	16.173	5.183	12.29	3.94
Gyro rake	4.05	1.71	4.12	13.221	7.731	9.98	5.84
	6.24	2.23	4.26	13.670	6.130	10.03	4.50
	7.50	2.46	4.39	14.087	5.726	10.08	4.10
	9.61	2.76	4.50	14.440	5.231	10.12	3.67
Manual rake (one man)	-	0.08	-	-	-	1.25	15.00

CONCLUSIONS

From the above results, the following conclusions are drived:

1- In general, the increment in forward and rotational speeds increases the mechanical losses for both rotary and gyro rake machines. However, the maximum values of mechanical losses were 2.53 and 2.91% at forward and rotational speeds of 9.61 km/h and 790 r.p.m. with hay moisture content of 23.67% (w.b.) for the above mentioned two machine, respectively.

2- Rotary tedder gave the highest value of crude protein retention. It was reached 91.84% at forward and rotational speeds of 4.05 km/h and 505 r.p.m. with hay moisture content of 46.18% (w.b.).

3- The minimum value of mechanical losses were obtained by using rotary tedder machine. It was reached 0.57% at forward and rotational speeds of 4.05 km/h and 505 r.p.m. with hay moisture content of 46.18% (w.b.).

4- Rotary tedder was considered the superior machine in reducing mechanical losses and obtaining the highest values of crude protein retention.

5- The increment in forward speed decreases the unit energy where as, the minimum values of unit energy were 4.751 and 4.918 kW.h/ fed at forward and rotational speeds of 9.61 km/h and 505 r.p.m. at hay moisture content of 23.67% (w.b.) for rotary tedder and gyro rake, respectively.

6- From the cost point of view it can be pointed out that manual raking cost is about 3.1 and 3.3 times of rotary and gyro rake machines, respectively.

REFERENCES

A.O.A.C. "Association of Official Analytical Chemists" (1984). Official methods of analysis. 14 th ed., 611 Arlington, U.S.A.

Buckmaster, D.R. (1993). Alfalfa raking losses as measured on artificial stubble. Trans. of the ASAE, 36 (3): 645-651.

Buckmaster, D.R.; C.A. Rotz and J. R. Black (1990). Value of alfalfa losses on dairy farms. Trans. of the ASAE, 33 (2): 351-360.

Dobie, J.B.; J.R. Goss; R. A. Kepner; J.H. Meyer and L.G. Jones (1963). Effect of harvesting procedures on hay quality. Trans. of the ASAE, 6(4) 301-302.

Embaby, A. T. (1985). A comparison of different mechanization systems for cereal crop production. Unpub. M. Sc. Thesis. (Agric. Mech. Dept.), Cairo Univ.

Gihad, A.A. (1963). Some studies on the improvement of the feeding value of clover and its hay. Ph. D. Thesis, Ag. Sc. (Animal nutrition Dept.), Fac. of Agric., Cairo Univ., Egypt.

Hunt, D. (1983). Farm power and machinery management. 8 th ed., Iowa State University Press, Ames. U.S.A., : 148-165.

Kepner, R.A.; R. Bainer and E.L. Barger (1982). Principles of farm machinery. Textbook, 3rd ed., The AVI Published Co. Inc., Westport, Connecticut: 331-340.

Kholief, R.M. (1989). Study on forage harvesting machines. Unpub. M. Sc. Thesis, Fac. of (Agric. Mech. Dept.), Kafer El-Sheikh, Tanta Univ., Egypt.

Koegel, R.G.; R.J. Straub and R. P. Walgenbach (1985). Quantification of mechanical losses in forage harvesting. Trans. of the ASAE, 28 (4): 1047-1051.

Moser, L.E. (1980). Quality of forage as affected by post-harvest storage and processing. "Crop Quality Storage and Utilization". American Society of Agronomy, Madison, WI.

Rotz, C.A. And S.M. Abrams (1988). Losses and quality changes during alfalfa hay harvest and storage. Trans. of the ASAE, 31 (2): 350-355.

Savoie, P.; C. A. Rotz; H.F. Bucholtz and R.C. Brook (1982). Hay harvest system loss and drying rates. Trans. of the ASAE, 25 (3): 581-585, 589.

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الملخص العربي

التجميع الميكانيكي للدريس تحت الظروف المحلية

د. رزق محمد خليف* - د. رفاعي رفاعي ابو شعيشع* - د. إبراهيم صلاح الدين يوسف*

يهدف هذا البحث إلى تقييم أداء نوعين من آلات تجميع الدريس بعد عملية التجفيف بغرض كبسه وتخزينه وحتى يمكن تقديمة للحيوانات في صورة جيدة خلال الفترة الصيفية. ولتحقيق هذا الهدف تمت الدراسة علي نوعين من آلات تجميع الدريس تحت ظروف التشغيل الحقلي بمساحة ثلاثة أفدنه برسيم (صنف سخا ٣ الحشة الثالثة) بمزرعة محطة البحوث الزراعية بسخا للموسم الشتوي ٩٩/٢٠٠٠م.

وقد اشتملت الدراسة علي العوامل التالية

أ) نوع الآلة (آلة تجميع مركزي Rotary tedder دنماركية الصنع، آلة تجميع جانبي Gyro rake يابانية الصنع).

ب) السرعة الأمامية للآلة (٣,٠٥، ٦,٢٤، ٧,٥، ٩,٦١كم/ساعة).

ح) السرعة الدورانية لأذرع التجميع (٥٠٥، ٦٤٠، ٧٩٠ لفة /دقيقة).

د) المحتوي الرطوبي للدريس (٤٦,١٨، ٣٩,٤١، ٢٣,٦٧ ./° علي أساس رطب).

ويمكن تلخيص النتائج كما يلي:

١- أدت زيادة السرعة الأمامية إلى زيادة السعة الحقلية الفعلية حيث بلغت ٣,١٢، ٢,٧٦ فدان/ساعة لكل من Rotary tedder ، Gyro rake علي الترتيب.

٢- وصلت قيمة الفقد الميكانيكي أثناء عملية التجميع إلى ٢,٥٣ ./° عند سرعة أمامية ٩,٦١كم/ساعة ، و سرعة دورانية ٧٩٠ لفة/ دقيقة ، ومحتوي رطوبي للدريس ٢٣,٦٧ ./° علي أساس رطب بالنسبة للآلة Rotary tedder. بينما كانت ٢,٩١ ./° تحت ظروف التشغيل السابقة بالنسبة للآلة Gyro rake.

٣- أوضحت النتائج أيضا أن اكبر نسبة احتفاظ بالبروتين كانت ٩١,٨٤ ./° عند سرعة أمامية ٤,٥١ كم/ ساعة ، وسرعة دورانية ٥٠٥ لفة /دقيقة ، ومحتوي رطوبي للدريس ٤٦,١٨ ./° علي أساس رطب بالنسبة للآلة Rotary tedder. بينما كانت ٨٨,١٣ ./° تحت ظروف التشغيل السابقة بالنسبة للآلة Gyro rake.

٤- أظهرت البيانات أن الطاقة اللازمة لعملية تجميع الدريس عند اقل فقد ميكانيكي واعلي نسبة احتفاظ بالبروتين كانت ٧,٥٣٧ كيلو وات ساعة/فدان عند سرعة أمامية ٤,٠٥ كم/ساعة ، وسرعة دورانية ٥٠٥ لفة/دقيقة ، ومحتوي رطوبي للدريس ٤٦,١٨ ./° علي أساس رطب بالنسبة للآلة Rotary tedder.

٥- أدت عملية تجميع الدريس آليا إلى إنخفاض التكاليف بمقدار ٦٨ ./° بالمقارنة بعملية التجميع اليدوي.

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