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Study some Factors Affecting the Design of Rice Straw Bales Chopper

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ABSTRACT

This research aims to study effects of some factors on design of rice straw-bales chopper to solve the operation problems such as un-continuous rice-straw feeding rate to a cutting unit, the feeding-platform height and the rice-straw cutting size. The experiments were conducted to determine the optimum operation factors to achieve the straw lengths desired for the animal feeding and compost. The studied factors were type of knives (free, fixed-curved and free fixed-curved), chopping-drum speeds of 1450, 1750, 2050 and 2350 rpm (34.16, 41.23, 48.3 and 55.37 m/s) and feeding-mechanism speeds of 0.26, 0.31, 0.35 and 0.42 m/s. The Experiments recorded that increasing chopping-drum speed from 1450 to 2350 rpm, decreased the mean straw cutting-length from 9.12 to 4.92, from 7.95 to 3.65 and from 7.31 to 3.31 cm using free, fixed-curved and free fixed-curved knives type respectively at all tested feeding-mechanism speeds. The maximum chopper productivity of 1.2 Mg/h was recorded by using chopping-drum speed of 2350 rpm and feeding-mechanism speed of 0.42 m/s, meanwhile, the minimum chopper productivity of 0.92 Mg/h was recorded by chopping-drum speed of 1450 rpm and feeding-mechanism speed of 0.26 m/s at all cutting-knives type. The results revealed that increasing chopping-drum speed from 1450 to 2350 rpm, increased the chopper power-requirement from 3.51 to 7.12, from 4.15 to 7.75, and from 4.78 to 8.23 kW, while, increasing chopping-drum speed from 1450 to 2350 rpm, the chopper specific-energy increased from 3.81 to 5.93, from 4.5 to 6.46 and from 5.19 to 6.86 kW.h/Mg by using free, fixed-curved and fixed-curved knives type respectively at all tested feeding-mechanism speeds.

INTRODUCTION

Recently, rice straw became very important residues for animal fodder processing because of scarcity of the animal fodders in summer season. The farmers compress rice straw into bales and storage them. The rice-straw bales were chopped to be used to animal-fodders or compost processing. The baling method of rice straw on-field helps farmers to save the straw from weather changes, makes handling and transportation easier, facilitates its easy and safe storage and maintains its quality, Steele *et al.* (2009). Abo-Elasaad (2016) mentioned that the chopping rice-straw is very necessary as a pretreatment for different purposes. The chopping treatment was done to convert the straw into small pieces, which were suitable for animal feeding and compost processing. The rice-straw chopping can be done using varying types of chopping machines, but the productivity of these chopping machines is still little, not covering the manufactures needs, in addition to the high operation and production cost of the chopping process. Handling rice-straw bales in the processing places required more labor to remove rice-straw bales twines and feed it to chopping machines, leading to increase the production costs. Sugandi *et al.* (2018) mentioned that one of the alternatives to utilize rice straw as a pre-material to make compost. The results indicated that the rice straw should be cut into small size of 5 - 10 cm. It was found that the average diameter, length, moisture content and bulk density of rice straw are 0.4 cm, 70.8 cm, 34.6 % wet basis and 160.6 kg/m^3. AL-Gezawe *et al.* (2016) found that the maximum chopping-length average value of rice straw of 7.1 cm was obtained by using hammers-type at speed of 560 rpm. Meanwhile, the minimum chopping-length average value of rice straw of 1.54 cm was obtained by using knives and hammers-type at speed of 1040 rpm. Okasha (2016) recorded that increase the cutting drum-speed from 1200 to 2000 rpm, increase the cutting efficiency from 87 to 91.6, from 82.9 to 85.5 and from 82.4 to 84.9 % at moisture content of 8, 10 and 12 % respectively, and increased the chopper productivity from 0.41 to 0.49 Mg/h at the moisture content of 8 %. Yehia and Omran (2018) found that increasing cutting speed from 800 to 1400 rpm, decreased the cutting-length average 7.16, 7.53, 7.51, 6.38 and 7.98 % for tree-branch diameters of 30, 40, 50, 60 and mixed respectively for all tree-branch moisture contents and clearances. Metwally *et al.* (2006) indicated that increasing cutting-drum speed from 0.75 to 1.88 m/s, increased the chopping length about 24.1 and 60.5 % for serrated and straight-edge shapes respectively. It was found that the minimum chopping-length of 1.0 cm was obtained at feeding speed of 0.28 m/s using cutting knives of serrated-edge shaped. El-Fatih *et al.* (2010) indicated that increasing the cutting drum-speed from 56.6 to 70.7 m/s, the power requirement increased from 2.15 to 3.4, from 3 to 4.2 and from 4.3 to 6.71 kW at 3.5, 2.5 and 0.9 cm concave-hole diameters respectively. Radwan *et al.* (2016) reported that increasing chopping drum-speed from 1150 to 1628 rpm, increased the power requirement from 1.74 to 3.27, from 1.92 to 3.37, from 2.15 to 3.47 and from 2.35 to 3.84 kW at different feeding rates of 159.49, 201.60, 283.15 and 336 kg/h respectively. Also, the specific energy increased from 13.19 to 25.34, from 11.38 to 20.00, from 8.99 to 15.69 and from 8.40 to 14.37 kW.h/Mg at the same previous feeding rates. The research objective is to determine the affecting factors of design a rice-straw bales chopper to reach the straw lengths suitable for the animal feeding and compost.

MATERIALS AND METHODS

Materials:

Modified rice-straw bales chopper: The rice-straw bales chopper before modification was developed by (Abo-Elasaad, 2016). Fig. 1. shows views of the rice straw-bales chopper after modification. The rice-straw bales chopper after modification consists of the following parts:

Frame: The frame of the bales chopper after modification was made of an iron sheet with 0.5 cm thickness. The frame has three parts: horizontal part, inclined part and brackets. The horizontal part length, width and height are 165, 90 and 29 cm respectively. The inclined part length, width and height are 90, 47 and 175 cm respectively with a tilt-angle of 75 degree with horizontal part. Two brackets were bolted with two sides of frame inclined part. The two brackets made of iron with 0.5 cm thickness, 82 cm length and 50 cm width. The second chopping-mechanism mounted on the two brackets by bearings.

Feeding mechanism: The feeding mechanism before modification (feeding platform) was modified to give continuous and uniform feeding of rice straw to a cutting unit. Also, the feeding mechanism height was designed to suit the human-body anthropometric dimension. The feeding mechanism parts are:

(a) Feeding conveyor: The length, width and thickness of feeding conveyor were 120, 80 and 15 cm respectively. The feeding conveyor mounted on the frame of machine by two U-arms and stands. The U-arms and stands made of iron angle with a cross-section of 5 x 5 x 0.3 cm. The U-arms have a width of 25 cm and a height of 20 cm. Each stand has a total length of 100 cm.

(b) Feeding claws: The feeding claws fitted on the front of feeding-conveyor for catching and dragging the rice-straw bale and feed it toward cutting mechanism. The feeding claws consists of claw discs and claw drum.

Chopping unit:

Fig. 2 shows a sketch of the chopping unit. The chopping unit was modified to minimize the cutting length and increase machine efficiency. The chopping unit consists of two drums as following:

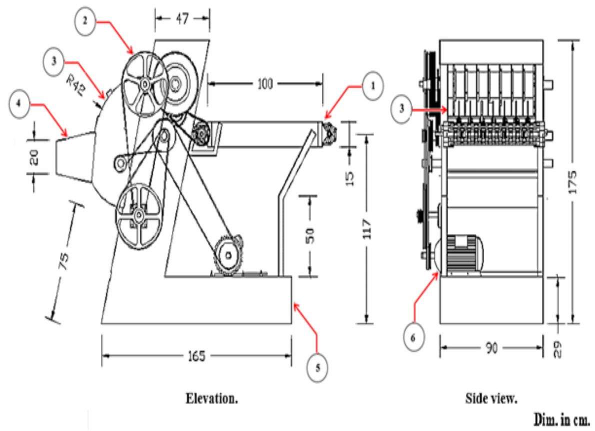

Fig. 1. The modified rice straw-bales chopper views
(1) Feeding mechanism, (2) Power transmission-unit, (3) Chopping unit, (4) Outlet duct, (5) Frame and (6) 20-hp electric motor.

(a) Cutting drum: The cutting drum was made of steel pipe with 16, 84 and 0.5 cm diameter, length and thickness respectively. Twenty-eight free cutting-knives were used. The free cutting-knives are made of steel with 0.7 cm thickness, 14 cm length, and 5 cm width. Four free cutting-knives were bolted between two flanges. The thickness and diameter of each flange are 0.7 and 24 cm respectively. The cutting fixed-knives bar was made of U-angle with 83 cm, 4 cm and 0.2 cm length, width and thickness respectively. The fixed knives (U-shape) were made of steel with 10 cm, 4 cm and 0.3 cm length, width and thickness respectively. The cutting fixed-knives bar fixed toward the cutting-drum direction with 1.5 cm clearance between each free and fixed knife.

(b) Chopping drum: The chopping drum mounted on the machine frame behind the cutting-drum. The horizontal and vertical distances between cutting and chopping drums are 36 and 19 cm respectively. The chopping drum was made of steel pipe with 16, 84 and 0.3 cm diameter, length and thickness respectively. Thirty-two free cutting knives and sixty-four fixed curved knives mounted on the chopping drum. The free cutting-knives were made of steel with thickness of 0.7 cm, length of 16 cm and width of 5 cm. Also, fixed-curved knives are made of spring steel with thickness of 0.3 cm, length of 15 cm and width of 5 cm. Eight fixed-curved knives were bolted around two flanges. Each free cutting-knife has two fixed curved-knives. Four free-cutting knives and eight fixed-curved knives were bolted with the two flanges. The two flanges are made of iron steel with outside and inside diameter and thickness of 24, 18 and 0.8 cm respectively. The flanges arranged on the chopping drum at equal spacing of 7 cm. The chopping-fixed knives bar was bolted with double solid-concave underneath the chopping-drum in front of outlet duct by 1.0 cm clearance between each chopping-knives group (free fixed-curved knives) and fixed knife. The chopping-fixed knives bar was made of iron plate with 83 cm length, 4 cm width and 0.3 cm thickness.

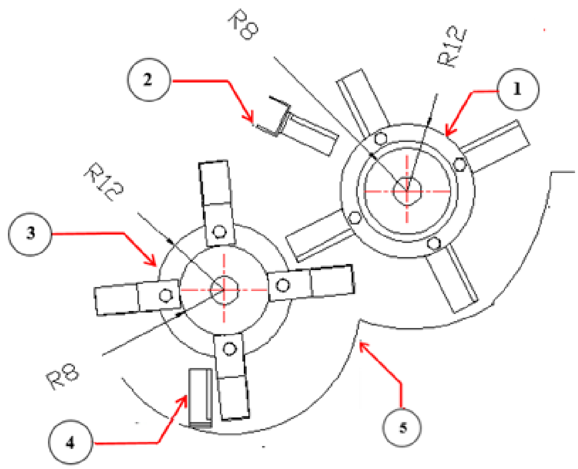

Fig. 2. Sketch of the chopping unit.
(1) Cutting drum, (2) Cutting fixed-bar, (3) Chopping drum, (4) Chopping fixed-bar and (5) Double solid-concave.

Double solid-concave: The double solid-concave was made of galvanized steel-sheet with 0.2 cm thickness, 89 cm width and 100 cm length. The double solid-concave has radii of 38 and 23 cm respectively. The double solid-concave was bolted underneath the chopping unit. The clearance between the cutting and chopping knives and double solid-concave was changed from 2.5 to 1.0 cm.

Outlet duct: The outlet duct was made of an iron-sheet with thickness of 0.2 cm. The inlet opening of the outlet duct has length of 80 cm and width of 30 cm. Meanwhile, the outlet opening of the duct has 60 cm length and 20 cm width. The depth of the outlet duct is 30 cm.

Electrical motor: Three-phase electrical motor of 20 hp (15.4 kW) and 1500 rpm was mounted on the frame to drive the modified machine using pulleys, v-belts, gears and sprocket wheel drives

Power transmission units: The power was transmitted from the electrical motor by pulleys, v-belts, gears and sprocket wheel drives. Table.1 shows tested power-transmission pulley diameters and speeds.

Table 1. Test chopping-drum shaft pulley diameters, cutting knives speeds, feeding claws handle-shaft pulley diameter and speeds and feeding-mechanism speeds.

Chopping-drum pulley diameter, cm.	Knives speed, rpm (m/s).	Feeding claws handle-shaft pulley diameter and speeds.	Feeding mechanism speed, rpm (m/s).
10.7	2350 (55.37)	30 cm and 65 rpm	18 (0.42)
12.3	2050 (48.30)	35 cm and 58 rpm	15 (0.35)
14.4	1750 (41.23)	40 cm and 51 rpm	13 (0.31)
17.3	1450 (34.16)	45 cm and 44 rpm	11 (0.26)

Rice straw-bales specifications: The specifications of tested straw bales were as follows:

- The bale length ranged from 100 to 120 cm. Meanwhile, the width and height of bale were 50 and 40 cm respectively.
- The bale density ranged from 55.46 to 65.5 kg/m^3.
- The rice straw-stem length in bale before chopping ranged from 30 to 40 cm.
- The bale mass ranged from 13.5 to 15.6 kg.
- The bale moisture content ranged from 15.3 to 17 %.

Methods:

Studied factors:

Experiments were executed to evaluate the performance of the modified chopper and determine the optimum operation factors. The rice straw-bales chopper was modified and tested in Rice Mechanization Center workshop, Meet El-Deeba, Kafr El-Sheikh Governorate through two sequence years of 2018 and 2019. The studied factors were as follows:

(a) chopping-drum speed: Four different speeds of chopping-drum of 1450, 1750, 2050 and 2350 rpm (34.16, 41.23, 48.3 and 55.37 m/s) were tested. Meanwhile, the cutting-drum speed was constant at 1260 rpm (26.4 m/s).

(b) Feeding-mechanism speed: Four different speeds of feeding-mechanism of 0.26, 0.31, 0.35 and 0.42 m/s were tested.

(c) Types of chopping-drum knives: Three different types of chopping-drum knives (free, fixed-curved and free fixed-curved) were tested.

Measurements:

(1) Straw cutting length average: The average of cutting length was measured from chopped rice straw sample of 100 g for each treatment. The four categories of < 3 , 3 – 6 , 6 - 12 and > 12 cm were measured, according to the different rice-straw uses (Arkoub, 2010).

(2) Productivity of chopping machine: The productivity was calculated using the next equation (Mady, 1999).

$$P = \frac{W}{t} \quad \text{.............................. (1)}$$

Where: (P) The productivity of chopping machine, Mg/h, (W) Mass of the rice straw-bale, Mg and (t) Time of chopping bale, h.

(3) Machine power-requirement and specific-energy: The required power of the modified machine with and without load was calculated using the next equation (Kurt, 1979):

$$P = \sqrt{3} \times I \times V \times \eta \times \cos\theta / 1000 \quad \text{.......................... (2)}$$

Where: (P) Machine power-requirement in kW, (I) Line current-intensity in A, (Cosθ) Power factor (equal 0.85), (V) Voltage being equal to 380 V, ($\sqrt{3}$) Three-phase coefficient current (equal 1.73) and (η) Motor mechanical-efficiency (assumed 95 %). The machine specific-energy was calculated using the next equation:

$$\text{Specific energy, kW. h/Mg} = \frac{\text{Power, kW}}{\text{Productivity, Mg/h.}} \quad \text{... (3)}$$

RESULTS AND DISCUSSION

Effect of tested factors on the straw-cutting length average.

Fig. 3 shows effect of chopping-drum speed on the straw-cutting length average at different feeding-mechanism speeds and type of knives. The results indicated that by increasing chopping-drum speed, the straw cutting-length average decreased. Meanwhile, by increasing feeding-mechanism speed, the straw cutting-length average increased at all type of cutting knives. The maximum cutting-length average of 9.12 cm was obtained by using free-knives type at chopping-drum speed of 1450 rpm (34.16 m/s) and the speed of feeding mechanism of 0.42 m/s. Meanwhile, the minimum value of cutting length average of 3.31 cm was obtained by using free fixed-curved knives type at the chopping-drum speed of 2350 rpm (55.37 m/s) and feeding-mechanism speed of 0.26 m/s. The decrease straw cutting-length average by increasing chopping drum-speed is due to increase number of chopping knives peats to rice stalks per unit time. Meanwhile, by increasing feeding-mechanism speed increased straw cutting-length average this is due to increase rice-straw feeding rate.

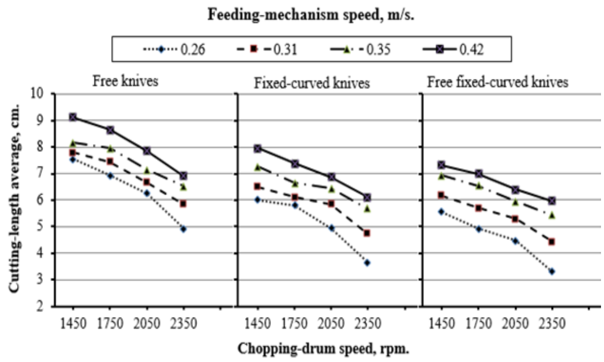

Fig. 3. Effect of chopping-drum speed on the straw cutting-length average at different feeding-mechanism speeds and type of knives.

Effect of tested factors on the chopping productivity.

Fig. 4 shows effect of chopping-drum speed on the chopping productivity at different feeding-mechanism speeds. The results revealed that by increasing chopping-drum and feeding-mechanism speeds, the chopping productivity increased. The maximum chopping productivity of 1.2 Mg / h was recorded by using chopping-drum speed of 2350 rpm (55.37 m /s) and feeding - mechanism speed of 0.42 m /s at all cutting-knives type. While, the minimum chopping productivity of 0.92 Mg/h was recorded by chopping-drum speed of 1450 rpm (34.16 m /s) and feeding-mechanism speed of 0.26 m/s at all cutting-knives type. Increasing of chopping productivity by increasing chopping-drum and feeding-mechanism speeds is due to decrease of chopping time and increase of rice-straw chopped mass.

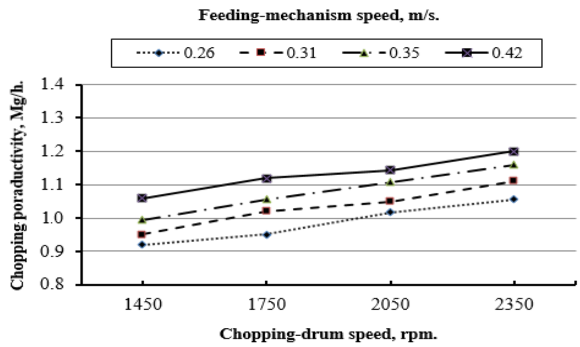

Fig. 4. Effect of chopping-drum speed on the chopping productivity at different feeding-mechanism speeds.

Effect of tested factors on the machine power requirements and specific energy.

Figs. 5 and 6 show effect of chopping-drum speed on the machine power-requirements and specific energy at different feeding-mechanism speeds and type of knives. The results revealed that increasing chopping drum and feeding mechanism speeds, the machine power requirements and specific energy increased at all cutting knives-type. The maximum values of power requirements and specific energy of 8.24 kW and 6.86 kW.h/Mg were achieved using free fixed-curved knives type at chopping-drum speed of 2350 rpm (55.37 m/s) and feeding-mechanism speed of 0.42 m/s. While, the minimum values of power requirements and specific energy of 3.51 kW and 3.81 kW.h/Mg were obtained by using free knives type at chopping-drum speed of 1450 rpm (34.16 m /s) and feeding-mechanism speed of 0.26 m/s. The increasing of the chopping-drum speed increased the torque on the cutting knives-shaft. While, increasing speed of feeding mechanism led to increase the resistance of rice-straw faced to cutting knives. Therefore, it was found an increment in the power requirements.

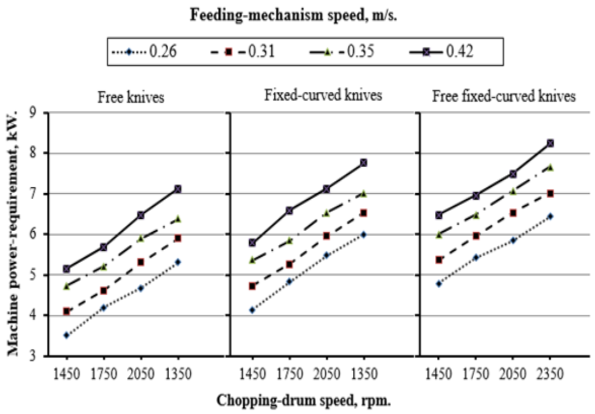

Fig. 5. Effect of chopping-drum speed on the machine power requirements for different feeding-mechanism speeds and type of knives.

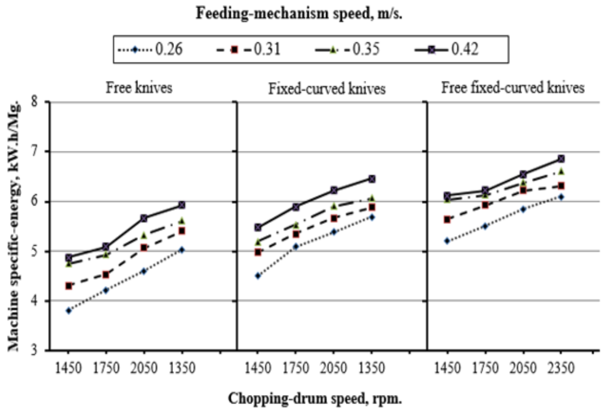

Fig. 6. Effect of chopping drum-speed on the machine specific-energy for different feeding-mechanism speeds and type of knives.

CONCLUSION

The optimum operation factors were the chopping-drum speed of 2350 rpm (55.37m/s), type of cutting knives of free fixed-curved and feeding-mechanism speed of 0.26 m/s. The results data after using the optimum factors were the straw cutting length-average about 3.31 cm, the chopper productivity of 1.06 Mg/h, the power requirements about 6.43 kW and specific-energy 6.09 kW.h/Mg.

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دراسة بعض العوامل المؤثرة في تصميم آلـة فـرم بـالات قـش الأرز

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يعتبر قش الأرز من أهم المخلفات الزراعية التي أمكن الاستفادة منها مؤخراً في العديد من المجالات المختلفة أهمها صناعة الأعلاف والسماد العضوي بعد أن كان أهم مصادر تلوث البيئة في مصر. يتم تجميع القش في شكل بالات بالحقل حتى يسهل تداوله وتخزينه لحين استخدامه على مدار العام. استخدام القش في صناعة الأعلاف أو السماد العضوي يتطلب تقطيعه بأطوال محدده تتناسب مع المنتج المراد تصنيعه. لذا كان الهدف من هذه الدراسة تطوير آلة تقطيع القش (أبوالأسعاد ٢٠١٦) من حيث جهاز تغذية منتظمة وجهاز فرم ثنائي المراحل بسكاكين متنوعة وفتحة خروج موجه لتجميع ناتج الفرم. تم تصنيع واختبار الآلة المطورة في مركز ميكنة الأرز بميت الديبة ـ معهد بحوث الهندسة الزراعية ـ محافظة كفر الشيخ. وقد تم دراسة مجموعة من العوامل يمكن تلخيصها فيما يلي:١- أربع سرعات مختلفة لدرفيل الفرم وهي: ١٤٥٠، ١٧٥٠، ٢٠٥٠، ٢٣٥٠ لفة/دقيقة، (٣٤,١٦، ٤١,٢٣، ٤٨,٣، ٥٥,٣٧ م/ث).٢- ثلاث أنواع لسكاكين الفرم وهي: تجميعه من السكاكين الحرة مع سكاكين منحنية مثبتة على الدرفيل، سكاكين منحنية مثبتة على الدرفيل فقط وسكاكين حرة فقط.٣- أربع سرعات لجهاز التغذية وهى: ٠,٢٦، ٠,٣١، ٠,٣٥ و٠,٤٢ م/ث. اهم النتائج المتحصل عليها:١- أقل متوسط طول للقش المقطوع ٣,٣١ سم باستخدام تجميعه السكاكين الحرة مع السكاكين المنحنية ـ عند سرعة سكاكين لدرفيل الفرم ٢٣٥٠ لفة/دقيقة (٥٥,٣٧ م/ث) وسرعة جهاز التغذية ٠,٢٦ م/ث. في حين أقصى متوسط طول للقش المقطوع ٩,١٢ سم باستخدام السكاكين الحرة عند سرعة سكاكين لدرفيل الفرم ١٤٥٠ لفة/دقيقة (٣٤,١٦ م/ث) وسرعة جهاز التغذية ٠,٤٢ م/ث.٢- أقصى متوسط لإنتاجية الآلة ١,٢ ميجا جرام/ساعة باستخدام سرعة سكاكين درفيل الفرم ٢٣٥٠ لفة/دقيقة (٥٥,٣٧ م/ث) وسرعة جهاز التغذية ٠,٤٢ م/ث. بينما اقل متوسط إنتاجية للآلة ٠,٩٢ ميجا جرام/ساعة تحقق باستخدام سرعة سكاكين لدرفيل الفرم ١٤٥٠ لفة/دقيقة (٣٤,١٦ م/ث) عند سرعة جهاز التغذية ٠,٢٦ م/ث.٣- أقصي قيم لمتطلبات القدرة والطاقة النوعية ٨,٢٤ كيلو وات ،٦,٨٦ كيلو وات. ساعة/ميجا جرام عند استخدام تجميعه السكاكين الحرة مع السكاكين المنحنية وسرعة سكاكين لدرفيل الفرم ٢٣٥٠ لفة/دقيقة (٥٥,٣٧ م/ث) مع سرعة جهاز التغذية ٠,٤٢ م/ث. بينما اقل قيم لمتطلبات القدرة والطاقة النوعية ٣,٥١ كيلو وات، ٣,٨١ كيلو وات. ساعة/ميجا جرام سجلت عند استخدام السكاكين الحرة مع سرعة سكاكين لدرفيل الفرم ١٤٥٠ لفة/دقيقة (٣٤,١٦ م/ث) وسرعة جهاز التغذية ٠,٢٦ م/ث. وبناءاً على ما سبق فإن آلة فرم بالات القش بعد التعديل مناسبة لتجهيز قش الأرز لتصنيع الأعلاف والسماد العضوي تحت الظروف المصرية مع مراعاة عوامل التشغيل الموصي بها.