Evaluate the Modified Chopper for Rice Straw Composting

A. Elfatih, E. M. Arif, and Atef, A. E.

1National Research Center, Dokki, Cairo, Egypt

Abstract: Crop residues are considered among the most important materials in Egypt especially rice straw. There are many types and models of choppers in Egypt to assist in recycling the field crop residues. One of the chopper machines which are imported has many problems such as size of cut and throwing the cut materials. The present research work was conducted at Gimaza research station, Gharbia Governorate to evaluate the machine performance in cutting rice straw for composting because of evaluation is the final proof of a successful design. The modified machine was fabricated and evaluated under the supervision of Agricultural Engineering Research Institute and National Research Center. Cutting drum speed and concave holes diameter affect the cutting efficiency, chopper productivity, power requirement, energy consumption and composting period. Increasing the cutting drum linear speed from 56.6 m/s to 70.7 m/s, increased the cutting efficiency, the chopper productivity, and the power requirement by percentage of 3.7%, 2.8% and 0.9%, 57.5%, 55.9% and 41.7%, 36.8%, 28.6% and 35.9%, respectively, meanwhile, decreased the energy consumption by percentage of 32.7%, 38.4 and 9% for 35 mm, 25 mm, and 9 mm concave hole diameter, respectively. The shortest composting period 95 days has been resulted using 25 mm concave holes diameter at 66 m/s cutting drum speed, meanwhile the longest period 140 days has been resulted using the 9 mm concave holes diameter at 70.7 m/s cutting drum speed. Also, it has been resulted using the 35 mm concave holes diameter at 56.6 m/s cutting drum speed. The highest cost was 240.7 L.E./ton, Meanwhile the lowest cost was 129.2 L.E./ton.

Kew words: Modified chopper, chopping rice straw and compost

INTRODUCTION

Rice straw is considered as the one of the main environmental problems in Egypt. It is estimated to be around 2 million tons every year [1]. Nowadays, many different types of machines are imported locally modified or manufactured for chopping process. El-Saadany [2] concluded that the percentage of cutting efficiency increased with increasing the numbers of helical shaft revolution until it reached the maximum cutting efficiency. The cutting efficiency increased with increasing edge angle from 21° to 24°, while it decreased with increasing edge angle from 24° to 27° at the same helical shaft speed. Jekendra and Singh [3] reported that the energy requirement of various fodder harvesting machines differ significantly from those of net cutting. Crop acceleration, compaction and conveyance normally consume more than 50% of total energy while energy consumed in shearing stems is normally less than 3%. A desired blade bevel angle ranging from 20° to 30° with a rake angle of 10° to 20° operating at speeds between 25 to 35m/s gives an optimum cutting energy requirement for forage materials having 35 % moisture content.

El-Iraqi and El-Khawaga [4] found that the maximum percentages in cutting length less than 5cm were 87.80 and 92% obtained for rice straw and corn stalks residues, respectively, at cutting speed of 10.09m/s, feeding rate of 0.771ton/h and knife clearance of 1.5mm. The maximum values of power consumption of 4.90 and 4.76kW were obtained at the same feeding rate and cutting speed with 4.5mm knife clearance for cutting rice straw and corn stalks, respectively. Parr, et al [5] stated that the components of rice straw are mainly cellulose and hemicellulose encrusted by lignin, in addition to a small amount of protein, which makes it high in C:N ratio. Therefore it is resistant to microbial decomposition compared to straw from other protein-rich grains such as wheat and barely. Reddy and Ohkura, [6]. Stated that the rice-straw was chopped to approximately 5 cm size and 60 to 70 kg of such chopped straw was moistened for a week by sprinkling water, and mixing frequently. Three replicates each with 5 kg of the moist straw were taken in separate rectangular plastic containers of size 35 x 45 x 20 cm. Twenty individuals of each species of earthworms were introduced in each replicate container. Simultaneously, rice-straw (5 kg) was composted
normally without any earthworm in another set of three replicate containers. After about 75 days, the vermicomposts prepared with the earthworm species and the normal compost were collected in polyethylene bags. Samra et al. [7] stated that the effective management of post harvest rice straw is perhaps the biggest challenge facing intensive rice production in Egypt. Rice residues contain large quantities of silica and burning is the most cost-effective and the predominant method of disposal in areas under combined harvesting. Misra and Roy [8] reported that the composting is carried out in a corner of a field and in a circular or rectangular pit. Rice straw, animal dung (usually pig), aquatic weeds or green manure crops are used and often silt pumped from river beds is mixed with the crop residues. The pits are filled layer by layer, each layer being 15 cm thick. Usually, the first layer is of a green manure crop or water hyacinth, the second layer is a straw mixture and the third layer is of animal dung. These layers are alternated until the pit is full, when a top layer of mud is added; a water layer of about 4 cm depth is maintained on the surface to create anaerobic conditions which help to reduce losses of nitrogen. Approximate quantities of the different residues in tons per pit are: river silt 7.5, rice straw 0.15, animal dung 1.0, aquatic plants or green manure 0.75 and superphosphate 0.02. Three turnings are given in all, the first one month after filling the pit and, at this time, the superphosphate is added and thoroughly mixed in. Water is added as necessary. The second turning is done after another month and the third two weeks later. The material is allowed to decompose for three months and produces about eight tons of compost per pit.

The aim of the present work is to evaluate the modified chopper for chopping rice straw for composting.

MATERIALS AND METHOD

Machine specification: Stationary chopper driven by tractor PTO (power take off) shaft. Overall dimensions are 85 cm, width, 186.5 cm length, and 1960 cm height (Fig. 1).

The machine main frame, chopping house, and fan were fabricated from 5 mm sheet metal (st. 37). The chopping drum (Fig. 2) consisted of 50 mm main shaft diameter (st. 42), 18 cm steel pipe (st. 37), and flail type knives (spring steel). The knives were hardened and treated, also static and dynamic balance have been done for the chopping drum on 4500 rpm at special workshop. Conveyor shaft with universal joint was used to transmit the power from tractor PTO to the machine gear box (of ratio 1 : 7). System provided with flexible coupling (safety unit) supported between gear box and main shaft. The power transmitted from the main shaft to the feeding drum and fan through pulleys and belts.

Machine description: Rice straw is fed uniformly through feeding drum and tray then the chopping drum cut the straw by the effect of impact shear also inside the chopping house by the effect of tensile, friction, and impact effect in chopping process, then the cut pieces pass through the concave holes and suck by the centrifugal fan and throw out the machine.

Chopping material: The tested material was rice straw after combine harvester. Straw average length was 80cm (from 90 to 70 cm).

Experimental procedure: All experiments were carried out at different combinations of chopping cylinder peripheral velocity (3000, 2800, 2600, and 2400 rpm corresponding to 70.7, 66, 61.3, 56.6 m/s), different concave hole diameter (35, 25, 9 mm), and rice straw in the chopping process. In one complete experiment a test was carried out in the field to determine plants specifications, machine capacity, chopping power requirement, compost periods and cost. The other part of this experiment was carried out in the laboratory to determine the moisture content and the cut straw lengths.

Preparing the Raw Material for Running the Experiments: The raw material was collected by labors and it was left in the field until reach the desirable straw moisture content (around 15% to 13%) then it was collected in the form of heap to start the chopping process. After chopping process complete the cutting row material was mixed with 100kg manure, 15kg super-phosphate, and 15kg ammonia sulfate for one ton shredded materials. The all components were mixed together, and moved to curing area. Then the moisture content was maintained at 40-60% and covered. The curing turned over every 15 days manually (using labor) until reach maturity.

Cutting efficiency: Cutting efficiency was calculated by measuring the stem length before cutting and the size or length of particles after cutting. That according to the following equation:

\[ \zeta_c = \frac{(L_b - L_{af})}{L_b} \]

Where:

\[ \zeta_c = \text{cutting efficiency. ( } \% \text{).} \]

\[ L_b = \text{Residual length before cutting, cm.} \]

\[ L_{af} = \text{Particles length after cutting, cm.} \]
Power consumption: The power was calculated by using the following formula \[9\].

\[
P = \frac{W_f \cdot C.V. \cdot \eta_{th} \cdot 427}{75}, \quad \text{hp.}
\]

Where:
- \(W_f\) = rate of fuel consumption kg/sec.
- \(C.V.\) = calorific value of fuel in kcal/kg. (average C.V. of diesel fuel is 10000 kcal/kg).
- \(427\) = thermo mechanical equivalent, kg.m/kcal.
- \(\eta_{th}\) = thermal efficiency of the engine (considered to be 30% for diesel engine).

Energy: Estimation of the energy required was carried out using the following equation:-

Energy requirements (kW.h/ton) = (power requirements, kW)/(machine productivity, ton/h).

Costs: Costs are calculated to produce one ton of compost as follows:

RESULTS AND DISCUSSIONS

The chopping machine was tested with rice straw (after combine harvester). Nasr tractor 65 Hp was used to operate the machine.

Cutting efficiency: The relationship between cutting drum speed and cutting efficiency at different concave holes diameter are shown in Fig. (3). Cutting efficiency increased by increasing the cutting drum speed. By increasing the cutting drum speed from 56.6 m/s to 70.7 m/s, cutting efficiency increased from 93.8 % to 97.5 %, from 95 % to 97.8 %, and from 97.3 % to 98.2 % for 35 mm, 25 mm, and 9 mm concave hole Diameter, respectively. Also, cutting efficiency
increased by decreasing the concave holes diameter. By decreasing the concave hole diameter from 35 mm to 9 mm the cutting efficiency increased from 93.8 % to 98.2 %, respectively. That is may be due to decreasing the cut lengths of rice straw by increasing the cutting drum speed, also by decreasing the concave holes diameter.

**Productivity:** Fig. (4) Shows The relationship between cutting drum speed and chopper productivity at different concave holes diameter. Chopper productivity increased by increasing the cutting drum speed. By increasing the cutting drum speed from 56.6 m/s to 70.7 m/s, the productivity increased from 489 kg/h to 1150 kg/h, from 430 kg/h to 976 kg/h, and from 350 kg/h to 600 kg/h for 35 mm, 25 mm, and 9 mm concave hole diameter, respectively. Also, machine productivity increased by increasing the concave hole diameter. By increasing the concave hole diameter from 9 mm to 35 mm the machine productivity increased from 350 kg/h to 1150 kg/h, respectively. That is may be due to accelerate the cut materials by increasing the cutting drum speed, also by increasing concave hole diameter the cut materials pass easy through holes.

**Power Requirement:** Fig. (5) Reveals the effect of cutting drum speed on the power requirement at different concave holes diameter. Power requirement increased by increasing the cutting drum speed. By increasing the cutting drum speed from 56.6 m/s to 70.7 m/s, the consumed power increased from 2.15 kW to 3.4 kW, from 3 kW to 4.2 kW, and from 4.3 kW to 6.71 kW for 35 mm, 25 mm, and 9 mm concave holes diameter, respectively. Also, the consumed power increased by decreasing the concave holes diameter. By decreasing the concave hole diameter from 35 mm to 9 mm the consumed power increased from 2.15 kW to 6.71 kW, respectively. That is may be due to the natural effect of speed on power and to accelerate the cut materials by increasing the cutting drum speed, also by increasing concave hole diameter the cut materials pass fast and longest through holes, without need for more power for cutting.

**Energy Consumed:** Fig. (6) Shows the effect of cutting drum speed on the energy requirement at different concave holes diameter. Energy consumed decreased by increasing the cutting drum speed. By increasing the cutting drum speed from 56.6 m/s to 70.7 m/s, the consumed energy decreased from 4.4 kW.h/ton to 2.96 kW.h/ton, from 6.98 kW.h/ton to 4.3 kW.h/ton, and from 12.29 kW.h/ton to 11.18 kW.h/ton for 35 mm, 25 mm, and 9 mm concave holes diameter, respectively. Also, the consumed energy decreased by increasing the concave holes diameter. By increasing the concave holes diameter from 9 mm to 35 mm the consumed energy decreased from 12.29 kW.h/ton to 2.96 kW.h/ton, respectively. That is may be due to increasing the machine productivity by increasing the cutting drum speed, also by increasing concave holes diameter the machine productivity increased.

**Compost Maturity Period:** Fig. (7) Shows the effect of cutting drum speed on the consumed time to compost maturity at deferent concave holes diameter. Composting period varied by increasing the cutting drum speed. By increasing the cutting drum speed from 56.6 m/s to 70.7 m/s, the composting period increased from 105 days to 140 days, using the 9 mm concave holes diameter, meanwhile, the period decreased by increasing the cutting drum speed from 56.6 m/s to 66 m/s and increased by increasing the cutting drum speed from 66 m/s to 70.7 m/s. That is may be due to the interaction of cut lengths and curing aeration and their effect on the composting process. Also, the composting period was affected by the concave holes diameter. The shortest period 95 days was resulted using 25 mm concave holes diameter at 66 m/s cutting drum speed, meanwhile the longest period 140 days was resulted using the 9 mm concave holes diameter at 70.7 m/s cutting drum speed, also it was resulted using the 35 mm concave holes diameter at 56.6 m/s cutting drum speed.

**Costs:** Costs are calculated to produce one ton of compost as follows:

\[
\text{Costs} = \text{rice straw price} + \text{add materials price} + \text{chopping process cost} + \text{turning process cost} + \text{water cost} + \text{labor wages} + \text{ground area rental costs}
\]

Rice straw price @ 100 L.E. / ton.
Add materials price = 40 L.E./1 m³ (2009 price).
Chopping process cost = 20 L.E./h \[10\].
Turning process cost @ 1 L.E./each.
Water cost @ 1.6 L.E./1 m³ (2009 price).
Labor wages = 0.5 L.E./1 m³ day.
Ground area rental costs @ 0.125 L.E./ 1 m³ day.
The highest cost was 240.7 L.E./ton, Meanwhile the lowest was 129.2 L.E./ton.

**Conclusions:** Cutting drum speed and concave holes diameter have affected the cutting efficiency, chopper productivity, power requirement, energy consumption and composting period Evaluation is the final proof of a successful design\[1\].

By increasing the cutting drum speed from 56.6 m/s to 70.7 m/s, the cutting efficiency was increased by percentage of 3.7%, 2.8% and 0.9%, the chopper productivity was increased by percentage of 57.5%, 55.9% and 41.7%, and the power requirement was increased by percentage of 36.8%, 28.6% and 35.9%, and the energy consumption was decreased by percentage of 32.7%, 38.4% and 9% for 35 mm, 25 mm, and 9 mm concave hole diameter, respectively.
Fig. 3: The effect of cutting drum speed on cutting efficiency at different concave holes diameter.

Fig. 4: The effect of cutting drum speed on the chopper productivity at different concave holes diameter.

Fig. 5: The effect of cutting drum speed on the consumed power at different concave holes diameter.
By increasing the cutting drum speed from 56.6 m/s to 70.7 m/s, the composting period was increased from 105 days to 140 days, using the 9 mm concave holes diameter, meanwhile, the period was decreased by increasing the cutting drum speed from 56.6 m/s to 66 m/s and was increased by increasing the cutting drum speed from 66 m/s to 70.7 m/s.

The shortest composting period 95 days was resulted using 25 mm concave holes diameter at 66 m/s cutting drum speed, meanwhile the longest period 140 days was resulted using the 9 mm concave holes diameter at 70.7 m/s cutting drum speed, Also was resulted using the 35 mm concave holes diameter at 56.6 m/s cutting drum speed.

The highest cost was 240.7 L.E./ton, Meanwhile the lowest cost was 129.2 L.E./ton.

REFERENCES


