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Design, fabrication, and comparative evaluation of plant power shredder

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ABSTRACT

Fresh organic materials have to be shredded into smaller sizes to increase their decomposition rate. Hence, a plant shredder is necessary.

This study illustrates the importance of traditional or local knowledge to agriculture and natural resource management by providing households with adaptive strategies.

A plant shredding machine known as "Plant Power Shredder (PPS)" suitable for village-scale use was developed following the design criteria such as: portability, affordability, efficiency and versatility. The machine is 1.5mL×1.05m W×1.10m H, weighs 150kg and costs PHP75,000 (including 7hp Diesel engine). It is mounted in an angular bar framing, fitted with 2 free-wheeling wheels to be pulled by a hand-tractor. The prototype used combination of shear and impact forces through the combination of radially mounted blades and hammer-members.

Comparative evaluation of PPS was done with the RUMVD35000-16 and RUMVD35000-14 in terms of capacity, efficiency, fuel consumption, power-output ratio, sizes of shredded materials, percent decomposition of shredded output and break-even cost of each machine. Shredding was done on rice straw (RC 216), kakawate leaves and branches and dried coconut husk at three replications.

Results showed that PPS has the highest efficiency of 95.71%, lowest fuel cost of PHP57.17 per hour and PHP0.15 per kg, highest power to output ratio of 0.014hp per kg and lowest break even cost of PHP0.68 per kg. RU-14 has the highest capacity of 471.90kg per hour and has the greatest percentage of short-size shredded material of 70.94 %.

Keywords: shredder, organic, composting, compost, fertilizer

INTRODUCTION

The population explosion of today is posing a danger that indirectly brings sickness, famine and poverty (Lal 2001). Since the start of the modern world, the

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need for a sustainable food supply has been an urgent agenda by both the private and government sectors of the society (Mabogunje 1984, Mermut & Eswaran 2001). Attempts to increase the food supply through the use of chemical fertilizer was proven to be a temporary solution only (Saleque et al 2004). Agricultural findings revealed that continuous use of chemicals pollutes (Shamim Uddin & Kurosawa) depletes and makes the soil acidic (Sommer et al 2004). It also destroys the earthworm population which is responsible for fast decomposition of organic materials present in the soil. Ultimately, since the soil is not anymore productive- this results to farming system which is dependent solely on chemical-based mineral nutrients for plant growth (de Ridder et al 2004). Moreover, some forms of chemicals maybe absorbed in the system of the food crops which may not be eliminated during the process of cooking and may be taken in with the food and cause harmful effects on the human body (Singh et al 1997).

Organic farming is one of the approaches in the production of quality food crops which minimizes the use of chemical fertilizer (Gaur 1987). This is achieved by turning agricultural wastes into organic fertilizer (Barreira et al 2008) for plants (this is also called as recycling or composting). Recycling also prevents environmental pollution and at the same time, an economical means of increasing food production (Sharma 1994).

Today, the Department of Agriculture (DA) is developing ways and technology on the efficient and profitable use of organic fertilizers because it promotes better soil tilt and soil structure and thus provides an increase in yield. According to (Sangatanan & Sangatanan 1982), organic fertilizers (with animal manure) are the most valuable soil conditioner. It helps prevent soil erosion and crushing and cracking of the soil. Although it has low nitrogen (N), phosphorous (P) and potassium (K), it also supplies other essential micronutrients needed by the plants.

Organic fertilizers are from decomposed agriculture wastes such as rice straw, weeds, leaves, branches and roots of plants (Senesi 1989, Subosa 1992). These substrates should be chopped because shredding helps speed up decomposition by increasing the surface area available for microbial action and to provide better aeration (Tognetti et al 2007). If large quantities of substrates are to be used, plant shredder is needed (Barreira et al 2008, Luo et al 2009). Several shredding machines are now available in the country. However, most of them are suited only for commercial or business application because they are either for high volume application or stationary and are so expensive. These shredders are effective only for a specific type of raw material and inefficient to others. In selecting what machine to buy, it is important to know what type of shredder is most suitable and cost-effective for a given application. Thus, this study aimed to develop a trailer-type and versatile plant shredder, appropriate for village-scale application.

OBJECTIVES

The study was conducted to:

1. Design and fabricate a trailer-type plant shredding machine;
2. Evaluate the shredding performance of the machine;
3. Compare the performance of the machine with other commercially available shredders; and
4. Determine the financial indicators of the machine prototypes.

MATERIALS AND METHODS

Before the machine was conceptualized and developed, several design considerations were taken in order to satisfy the desired outputs.

Design Criteria

The general design criteria for the desired Plant Shredding machine were the following:

a. Can shred any type of plant material, especially stems and branches of about 2.54cm diameter;
b. Mobile, or trailer-type, so that it can be brought to different places in the village community;
c. Materials for fabrication are locally available; and
d. Can be fabricated in any local fabrication shops.

The specific design criteria for the plant shredding machine were:

Mobility: total mass should not exceed 200kg so that it can easily be pulled by a hand tractor, or be maneuvered manually by one person. It is also a trailer-type with 2 free-wheeling wheels from small cars. The machine is stable and could travel faster while towed for faster transport.

Shredding capacity: can produce volume of shredded materials equivalent with commercial brands in the market. It can shred any type of plant material such as fibrous materials (coco husk & rice straw) and stems and branches of about 2.54cm diameter.

Power source: should utilize engine with rated power commonly used in farm operations such as hand tractor, corn sheller, etc. so that the engine can be both used for shredding and for other farm operations. The engine can be removed easily and quickly for transfer to other farm implements.

Low Cost: the price of which is competitive with most common brands, affordable to small farmers or group of farmers in the community and has low operating cost.

Determination of Force and Kinetic Energy Requirement

The minimum force requirement was determined by using an improvised kinetic force test stand (Figure 1). The test stand was fabricated using 5.08x182.88cm long GI pipe and a 5.08cm diameter and 5.5kg solid steel shaft as piston. The pipe was secured vertically while the steel piston was placed inside the pipe. To determine the minimum force required to cut a 2.54cm diameter Kakawate stem, the stem was placed at the bottom, directly under the pipe. A piece of blade made from car leaf-spring was also vertically placed above the Kakawate stem, in cross sectional position. The steel piston was released at 4 different heights such as 100cm, 125cm, 150cm and 175cm representing 54N-m, 67N-m, 81N-m and 94N-m Kinetic energies, respectively. Each test height was done at three replications. The

Kakawate stem was cut by the blade as the steel piston hit the back portion of the blade. The degree of cut in the stem was visually determined and graded as 2 equal to 25% cut 3=50% cut, 4=75% cut, and 5=100% cut. The force requirement was determined by computing for the kinetic energy using the formula $K_e = mhg$, where m is the mass of the piston, *h* is the height in meters, and *g* is the gravitational acceleration equal to 9.8m per sec^2. Kinetic energy was expressed in N-m.

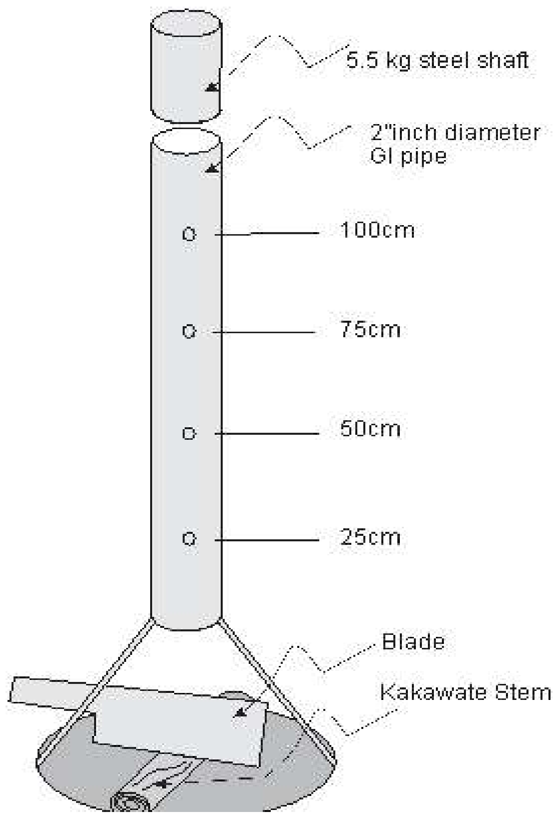

Figure 1. Assembly of the Kinetic Force Test Stand

Cutting Blade Design

Cutting blade orientation and conceptual design was considered before the other machine components were planned. Considering a left-handed knife used to cut cucumber, the design of the blade bevel orientation was also followed. The components involved in the cutting process were thought such as: the blade itself (its force, sharpness & bevel inclination), a force from the table opposing the direction of motion of the blade and the angle of orientation of the stem to that of the cutting blade. The angles of blade cutting, with respect to the cross-section of the stem such as 20^0 and 45^0 angles, were considered as it may affect the effectiveness of cutting.

Blade Minimum Power Requirement

The minimum power requirement was estimated based on the formula $P = T \times RPM$, where *T* is the Torque in N-m and *RPM* is the speed of the blade in Revolutions per Minute. Since the Torque required to cut the stem is equivalent to the Kinetic energy in Section 2**,** the Power required was therefore computed using the formula $P = K_e \times RPM$.

Moreover, considering that the desired machine could cut 3pcs of 2.54cm diameter stem simultaneously, the Kinetic energy required was multiplied by 3.

Flywheel Design

A flywheel was considered to be a part of the cutting energy for the blade to be effective in chopping plant stems. Its design considerations were: effective mass, velocity, simplicity of fabrication and space. The flywheel considered should be integrated into the shredding assembly system and can be fabricated in our local fabrication shop.

Computations of Flywheel Kinetic Energy

The flywheels' rotational speed was assumed at 2,500rpm, which can be achieved through combinations of belt and pulley transmission system. At normal operating condition with continuous speed of 2,000rpm in the engine shaft, the speed of the flywheel can be increased to 2,500rpm through combination of 10.16cm diameter pulley in the driving shaft and 7.62cm diameter pulley in the driven shaft. Using the flywheel kinetic formula $K_f = \frac{1}{2} m V^2$, the Kinetic energy of the flywheel was determined, where *m* is the mass of the flywheel and *V* is the peripheral velocity of the rim.

Machine Fabrication

The machine was fabricated using locally available materials in an ordinary welding shop with common machine tools and equipment. Simplicity was considered to ensure easy repair in the remote production areas.

Performance Evaluation

The performance of the developed plant shredding machine was evaluated in terms of shredding capacity in kg per hour, using mixed Kakawate leaves, stem and branches. Shredding capacity was measured by shredding a known volume of substrates and operating the machine at normal operating speed, while recording the total time of shredding. Angle of inclination in the feeding hopper with respect to the shredding blade was also considered, since this affects the effectiveness of cutting the stem. Fuel consumption was also measured following PAES Standard of measurement, which is done by filling the reservoir after each trial with fuel at the level previously determined (which represents the amount of fuel consumed).

Percent shredding efficiency was also measured by comparing the amount of shredded materials with the total raw samples using the formula $Eff = \frac{Ms}{Mt} \times 100$, where M_s is the mass of the shredded materials while M_t is the mass of the shredded materials while M_t is the total mass of the sample.

Comparative Evaluation

The developed Plant Shredder was evaluated in comparison with two RU Shredders available at VSU in terms of shredding capacity, fuel consumption, power to output ratio, percent decomposition of shredded materials and other financial indicators such as Break-Even Cost and Cost per kg of output.

The RU-16 shredder was powered by a 7hp KUBOTA diesel engine, which directly drives the machine's blade assembly through a belt-pulley transmission system (Figure 2). The machine consists of two sections, the hopper and the shredding or the chipping chamber. The hopper section is where the substrates to be shred are fed. It is provided with a feeding platform where the substrates are initially placed. The substrates are fed into the hopper, down to a system of rotating blades and are ejected to an outlet chute at the rear side of the shredding chamber.

Figure 2. RU Shredder (RUMVD35000-16)

The RU-14 shredder is smaller and similar in construction with the above-mentioned shredder (Figure 3). This machine uses 6.5hp gasoline engine, which directly drives the machine's shredding blades through a belt-pulley transmission system.

Figure 3. RU Shredder (RUMVD35000-14)

RU-14 also consists of the hopper and the shredding/chipping chamber. The hopper has an opening of 24cmx24cm and is provided with a feeding platform where the materials to be shred are initially placed. The materials are fed in the hopper, down to a system of rotating blades and are ejected to an 11cmx15cm outlet chute at the rear side of the shredding chamber.

The shredding/chipping section consists of the cylinder and the shredding assembly. The cylinder is made of casted steel, having a length of 37cm with a diameter of 25.3cm. Twigs and small branches to be chipped are fed to a 4cm diameter opening, which is at the side of the machine. There are 9 corrugated blades that are made of tempered abrasive plate, spaced at 1.5cm apart. The whole frame of the machine is about 45cmx160cmx105cm. The two machines mentioned above are both provided with 4 pieces of small removable wheels for maneuvering in concrete floor areas, but are not trailer-type. Although the three machines have different designs, fuel type and engine power, these were allowed to operate at their optimum operating condition to eliminate their specific advantages and disadvantages.

Economic/financial indicators of the machines were also based on their present conditions and cost to eliminate biases in the analysis.

Material Preparation

Rice straw, kakawate leaves and branches and dried coconut husks were used as organic materials for shredding. About 200kg each of freshly or newly threshed rice straws, kakawate leaves and branches and coconut husks were secured from the VSU main campus and neighboring barangays. Detailed information such as variety, source, etc. and physical conditions of the materials such as average length, diameter and moisture content (which may affect the shredding performance of the machines) were noted.

Experimental Procedures

Evaluation of the three shredders RUMVD35000-16, RUMVD35000-14 and Plant Power Shredder was done using three different substrates. Each substrate was replicated 3 times at 20kg, thus requiring 60kg of each substrate per machine. The study was conducted using three by three by three factorials, with the three machines as the main factor, three substrates as the sub-factors and at three-replications. Therefore, the evaluation was conducted with a total of 9 treatments and 27 runs. Table 1, below, shows the tabulated treatment combinations.

Table 1. Tabulated treatment combinations for shredding evaluation

Machine	Substrate	No. of Replications	Load per replication (kg)
RU shredder (RUMVD35000-16)	Rice straw	3	20
	Kakawate leaves and branches	3	20
	Coconut husk	3	20
RU shredder (RUMVD35000-14)	Rice straw	3	20
	Kakawate leaves and branches	3	20
	Coconut husk	3	20
Plant Power Shredder	Rice straw	3	20
	Kakawate leaves and branches	3	20
	Coconut husk	3	20
	Total	27	

Data Collections and Computations

During the performance evaluation of the machines, the following data were gathered:

1. The mean length of the substrate;
2. Mass of the substrate used before shredding;
3. The effective running time;
4. The total shredding time;
5. Fuel consumption; and
6. After a month, mass of the decomposed substrate.

The following evaluation parameters were determined:

Capacity of the Machine

The capacity of the three plant shredders were determined in terms of the mass of the substrate shredded per hour.

Machine's shredding capacity was computed using the formula:

$$C = \frac{w}{t} \qquad \text{(Equation 1)}$$

Where:

C = capacity of the machine, kg/hr
w = mass of the raw materials, kg
T = time of shredding the substrate, hr

Cost of Fuel Consumed

Before the start of each test trial, the fuel tank was filled with fuel to its full capacity and after each test, the fuel consumed was measured (PAES 209:2000). That is, volume of fuel consumed times cost of fuel, divided by the total operating time of the machine (Equation 2). Equation 3 computes the cost of fuel consumed per kilogram. This is equal to the volume of fuel consumed, multiplied by the cost of fuel and divided by the mass of shredded materials.

Cost of Fuel Consumed per Hour

$$FC = \frac{\text{Cost of fuel consumed, Php}}{\text{Total operating time, hr}} \qquad \text{(Equation 2)}$$

Cost of Fuel Consumed per Kilogram

$$FC = \frac{\text{Cost of fuel consumed, Php}}{\text{Mass of the raw material, kg}} \qquad \text{(Equation 3)}$$

Size Distribution of the Shredded Materials

To classify and describe the shredded materials from the three machines, a handful of sample was obtained randomly from each shredded substrate. This was weighed and segregated and classified into short (less than 3cm), medium (3–6cm) and long (those greater than 6cm). The substrates that belong to each category were also weighed to obtain its percentage of the total sample. That is, mass of category divided by the total mass of the sample, times 100.

Machine Efficiency

The efficiency of the machine was based on the effective shredding time and the total running time of the machine (Jeong & Phillips 2001). Effective shredding time is the time taken during the actual machine shredding operation. Using a stop watch, the time was stopped for any clogging and failure of the machine. Total running time was the length of time starting from feeding the materials until it was done, while effective shredding time was from feeding the materials until it was finished, without considering any possible failure of the machine during the operation. Thus, machine efficiency was obtained using the formula:

$$ME = \frac{EST}{TRT} \times 100 \quad \text{(Equation 4)}$$

Where:

ME = machine efficiency, %
EST = effective shredding time, hr
TRT = total running time, hr

Percent Decomposition

The shredded substrates were piled on the ground in a heap, under a shade. The heap was moistened occasionally to encourage bacterial action that is responsible for decomposition.

After a month and 17 days for rice straw and a month and 12 days for kakawate leaves and branches, the piled substrates were screened and weighed to determine the amount of organic fertilizer produced. The percentage of decomposition was equal to the mass of the decomposed materials over the total mass of the materials, multiplied by 100.

Break-even Cost (BEC) of the Shredding Machines

Break-even cost was determined using the fixed cost, variable cost and output capacity of the shredder (Henderson & Perry 1976).

In computing for the fixed cost, variable cost and break-even cost, the following equations were used:

The fixed cost:

$$FC = D + I + H + T + Ins \quad \text{(Equation 5)}$$

Where:

FC = annual fixed cost, P/yr
D = depreciation, P/yr
PC = purchase cost, P
SV = salvage value, P
I = interest on investment, P/yr
H = housing, P/yr
T = taxes, P/yr
Ins = insurance, P/yr

The variable cost:

$$VC = F + L + M \qquad \text{(Equation 6)}$$

Where:

VC = variable cost, P/hr
F = fuel, power and utilities, P/hr
L = labor, P/hr
M = maintenance, P/hr

The Total cost:

$$TC = FC + VC \qquad \text{(Equation 7)}$$

Break-even Cost:

$$BEC = \frac{\text{Total Cost (P/hr)}}{\text{Weight record compost (kg/hr)}} \qquad \text{(Equation 8)}$$

Power to Output Ratio

To determine the power requirement per output of shredded materials, Power to Output ratio was computed by dividing machine's engine-power with engine's capacity of each shredder by the machine's shredding capacity (mass of the raw material to be shredded).

Statistical Tools and Analysis

Data gathered were analyzed using an appropriate statistical program in a two-factor factorial Completely Randomized Design (CRD). Analysis of variance within the factors was determined for statistical significance.

F-test was also employed to determine the variations between individual treatments.

RESULTS AND DISCUSSION

Before the desired machine was fabricated, several information were taken into consideration for the detailed design, such as minimum kinetic energy to shred stem, minimum power requirement and flywheel kinetic energy.

Minimum Kinetic Energy Requirement

The kinetic energy requirement for cutting 2.54cm diameter kakawate stem was determined using the improvised test stand, as shown in Figure 4. Ninety four N-m have only cut 50% of the stem's diameter, while 81N-m have shown variable results. Some trials produced 100% stem cutting while some trials produced only about 75% cut. This result confirms that in order to cut 2.54cm diameter Kakawate stem, we need to have about 94N-m of Kinetic energy. For cutting 3pcs of stem simultaneously, this requires kinetic energy of 282N-m.

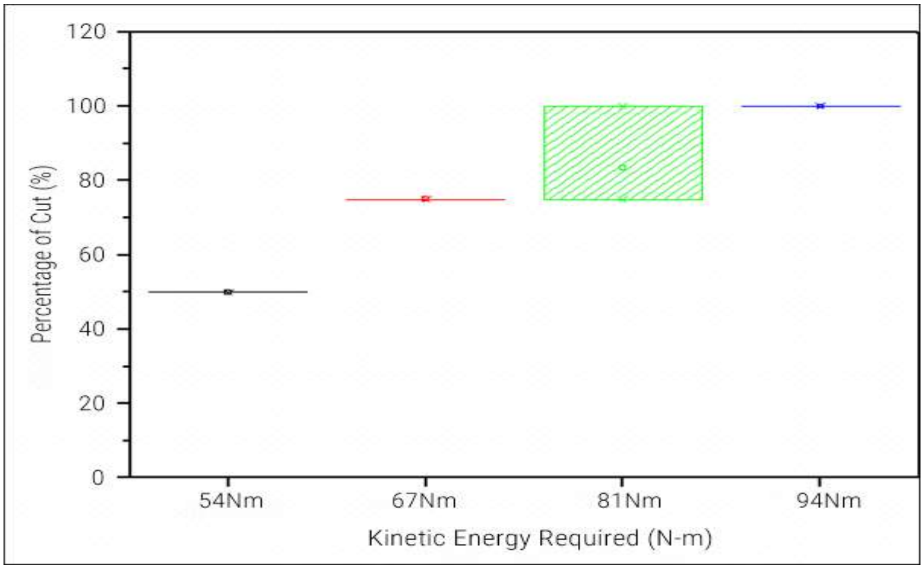

Figure 4. Determination of Minimum Kinetic Energy

Design of Cutting Blade

The design of cutting blade to cut the desired size of Kakawate stem is shown in Figure 5. The blade was made of hardened steel from car leafspring that is 2mm thick. The sharpened edge was beveled at one side, like a left-handed knife. A clearance of about 1mm between the blade and the base of the feeding hopper was also provided in order to cut thinner materials, such as fiber and leaves.

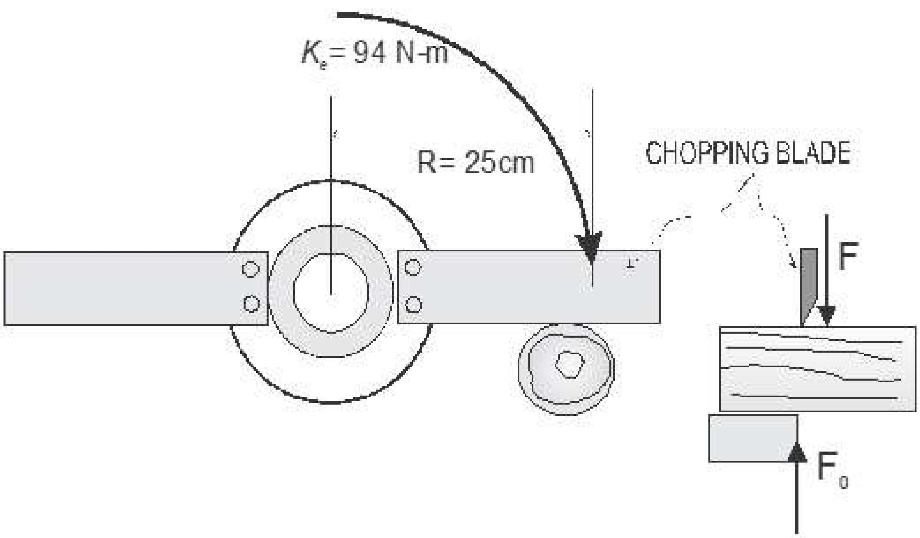

Figure 5. Design of Cutting Blade

Minimum Power Requirement

The minimum power requirement was determined considering that about 3pcs of 2.54cm diameter stems were cut simultaneously. Since 94N-m kinetic energy or torque was required to chop 1pc of stem, the torque requirement for 3 stems was 282N-m. From the formula of power $(P = T \times RPM)$, considering that the blade was rotating at 2,500RPM, the minimum power was 11.75KW or 16hp.

Flywheel Kinetic Energy

To reduce the power required in chopping the stem, a flywheel was integrated into the chopping blade in the same steel shaft. The flywheel was made of 12.7mm thick steel plate at 60cm diameter. Considering that the center of gravitational force of the flywheel was located at 25cm radius at 2,500rpm, then its peripheral velocity was 66.5m per sec. Solving for the kinetic energy of the flywheel using the formula, $K_f = \frac{1}{2}mV^2$, where *m* is the mass of the flywheel of 20kg, then the flywheel kinetic energy was 44,229N-m.

This flywheel kinetic energy (44,229N-m) plus the engine torque has provided enough energy to chop and shred even 3pcs of 2.54cm diameter kakawate stem simultaneously, which requires 282N-m of energy only, thus a load to energy ratio of about 1:157.

Design Drawing of Shredding Assembly

The design drawing of the shredding assembly is shown in Figure 6. The shredding assembly consists of the chopping and the hammer assemblies. Both the chopping blade assembly and the hammer assembly were secured in one steel shaft. Attached in the same shaft was the 20kg flywheel. The flywheel was provided also with a scraper made of flat bar material. The screen shown in the figure was secured in the housing assembly of the shredder. The screen ensures that the materials released into the exhaust chute were the right sizes. Moreover, the screen had fine clearance with the flywheel so that no materials greater than the holes of the screen would pass through. The scraper was made to rotate outside the screen to scrape off any material clinging to the screen and these materials were thrown outside through the exhaust chute.

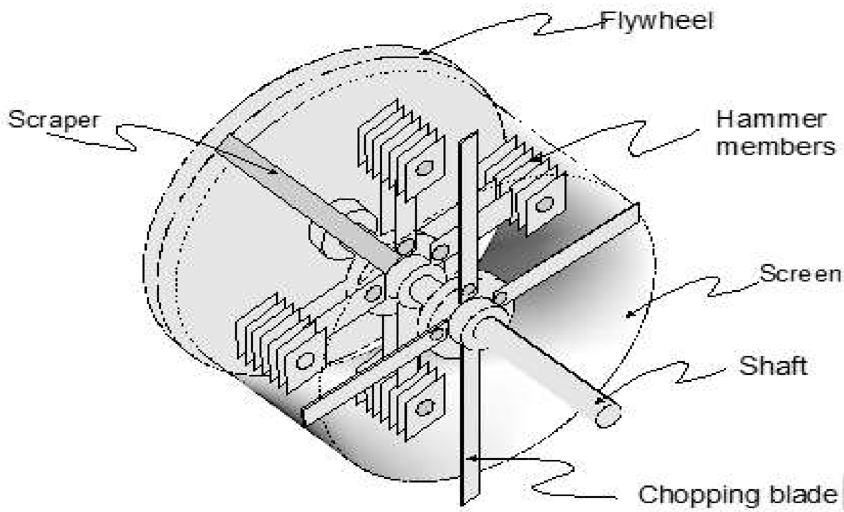

Figure 6. Details of shredding assembly

Design Drawing of the Plant Shredder

The overall design drawing of the plant shredder is shown in Figure 7. The machine had three major components such as: housing assembly, shredding assembly and power transmission assembly. The housing assembly secured all the other machine components to the frame. This consisted of the following components such as: angle bar framings, trailer hitch connections, chute and feeding hopper assembly and free-wheeling wheels assembly. The trailer hitch connection was provided with a retractable stand, which can be used at stationary position. The feeding hopper was made up of 1mm steel plate designed to form a trapezoidal funnel, while the exhaust chute was formed like an inverted smoke pipe. The free-wheeling wheel assembly consisted of the steel shafting, where the free-wheeling wheels were pivotically secured. Two pieces of angular members held the shaft in its position through U clamps. The two angular members were pivotically connected to the main frame. The shaft was also secured vertically through two motorbike shock absorbers. The absorbers ensured smooth travel of the whole system as it was being pulled by a car or a hand tractor.

The shredding assembly consisted of the chopping blade assembly, steel shaft, flywheel, screen and the hammer assembly, as shown in Figure 6. The power transmission on the other hand consisted of the prime mover (in this case, a 7hp diesel engine) and belt and pulley transmission assembly. The power of the engine was transmitted to the chopping blade and hammer assemblies through the belt and pulley transmission system. An idler clutch was also provided which raises the engine housing which is pivotically secured into the main frame.

Machine Fabrication

The machine was fabricated at the National Abaca Research Center (NARC) fabrication shop. Ordinary tools and equipment such as lathe machine, shaper, power hacksaw, electric drills, bench and portable grinders were used. Commercial parts such as shock absorbers, pillow block bearing, bolts, wheels, angle bars and engine were bought in Tacloban City. The flywheel was fabricated using 12.7mm steel and plate cut using an acetylene welding. Fabrication was completed with the assembling of the different parts and machine components.

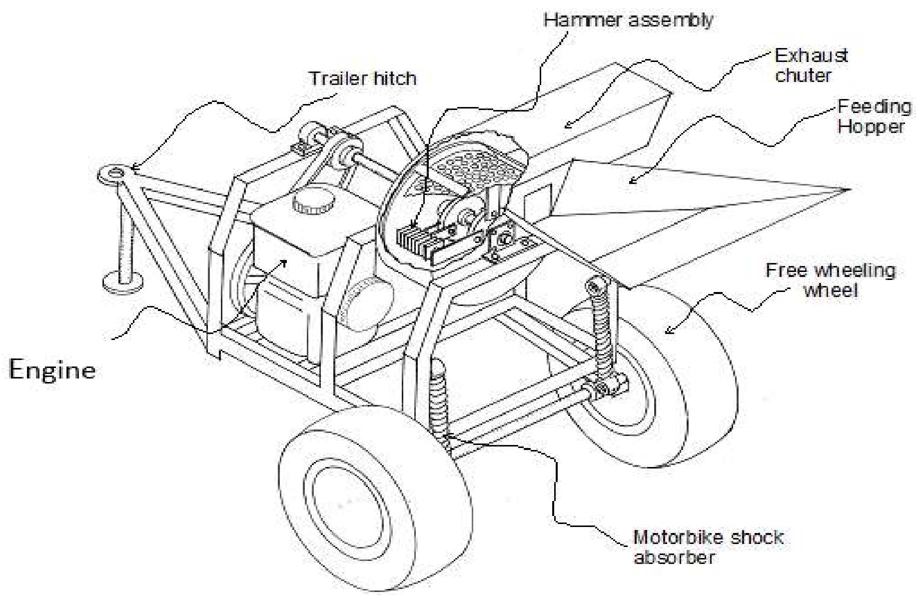

Figure 7. The isometric drawing of the design plant shredder

Description of the Machine

The developed plant shredding machine, known as Plant Power Shredder (PPS), was a trailer-type model with shock absorbers and 2 free-wheeling wheels, as shown in Figure 8 . It was powered by 7hp Yanmar L60AE-STM diesel engine, which was connected directly to the machine's chopping and shredding blades through a belt-pulley transmission system. The machine was about 1.5m long, 1.05m wide and 1.10m high. It weighed about 150kg and cost PHP75,000, including the 7hp diesel engine.

The machine was composed of a hopper and the shredding components which were responsible for a combined shearing and impact forces in shredding organic materials. The hopper was made of B.I. steel plate of 0.27cm thick, positioned at the axial side of the shredding chamber. Substrates to be shred were fed into the hopper down to the chamber, where a system of chopping blades and hammer blades were located. The shredded materials were ejected to an outlet chute of 13cmx20cm opening, located at the lateral side of the shredding chamber and perpendicular to that of the hopper. The shredding section consisted of the radially mounted blades and hammer blades. The two radially mounted chopping blades were positioned opposite each other, on a 3.55cm shaft. This provided a chopping action to the substrates. The blades were made of hardened and tempered steel (leaf spring) having a dimension of 6cmx15cmx0.8cm. The hammer blades, on the other hand, provided a crushing action to the substrates. It consisted of four bunches of hammer blades of dimensions 4cmx14cmx4cm. The bunch of the hammer blade was made of 11pcs of sharpened square plates of 4cmx4cmx0.4cm dimensions that are spaced 0.2cm apart.

Figure 8. Perspective view of the fabricated plant shredding machine

Testing and Evaluation

Using two angles (20^0 & 45^0) of the feeding hopper, the result of shredding capacity is shown in Figure 9. Forty five degree angle of the feeding hopper has slightly higher shredding capacity of about 850kg per hour. However, ANOVA results did not show any significant difference with respect to 20^0 angle, in terms of shredding capacity.

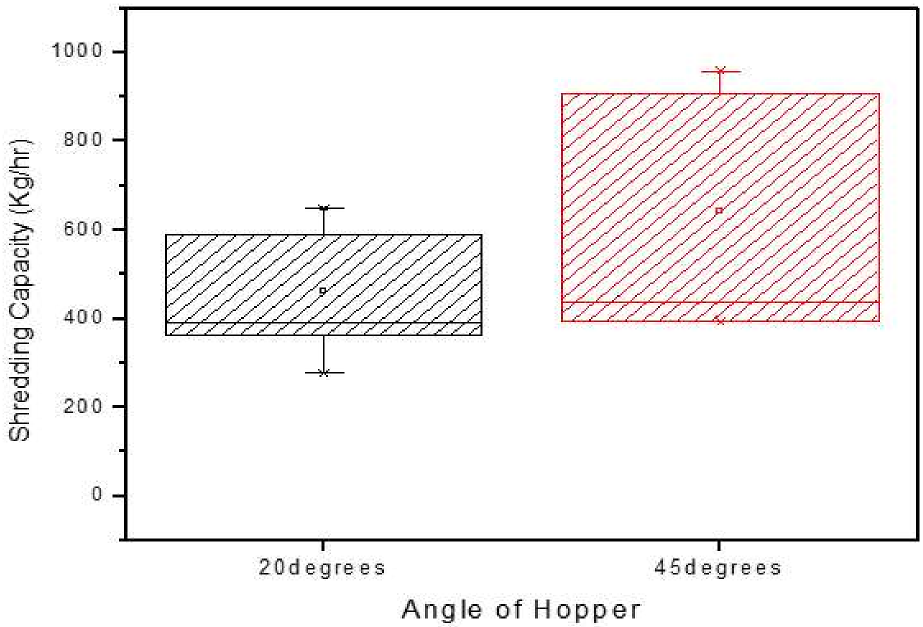

Figure 9. Shredding capacity at different angles of feeding hopper

In terms of fuel consumption (Figure 10), the 45^0 angle has also shown higher consumption of about 2.4L per hour, while the 20^0 angle has only about 1.8L per hour. ANOVA of both 20^0 and 45^0 angles did not show any significant variations in their fuel consumption.

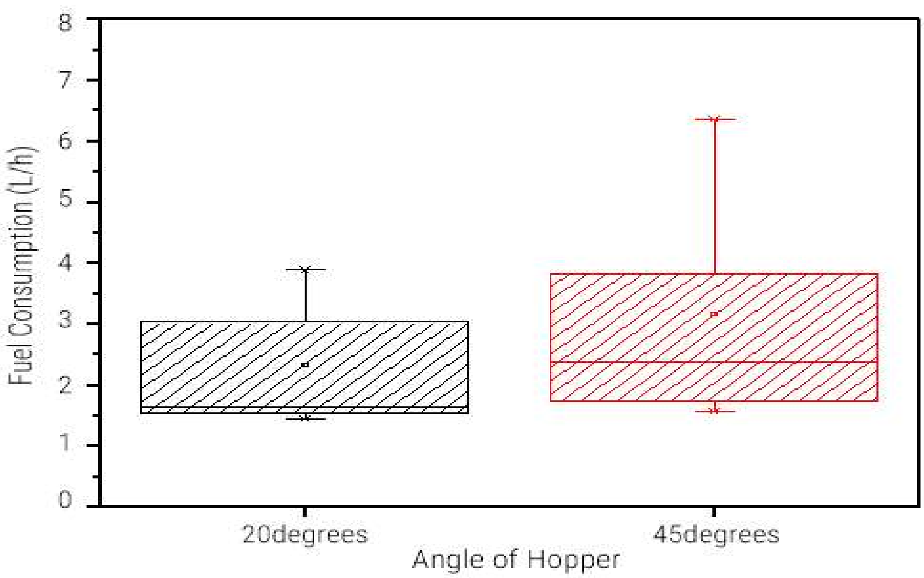

Figure 10. Fuel consumption at 20 and 45 degrees angle of the feeding hopper

The efficiency of the plant shredder at 20^0 and 45^0 angle of the feeding hopper are shown in Figure 11. The 20^0 angle of feeding hopper has slightly higher shredding efficiency of about 94%, while that of the 45^0 angle was about 89% efficient. However, this result did not give any significant difference through ANOVA.

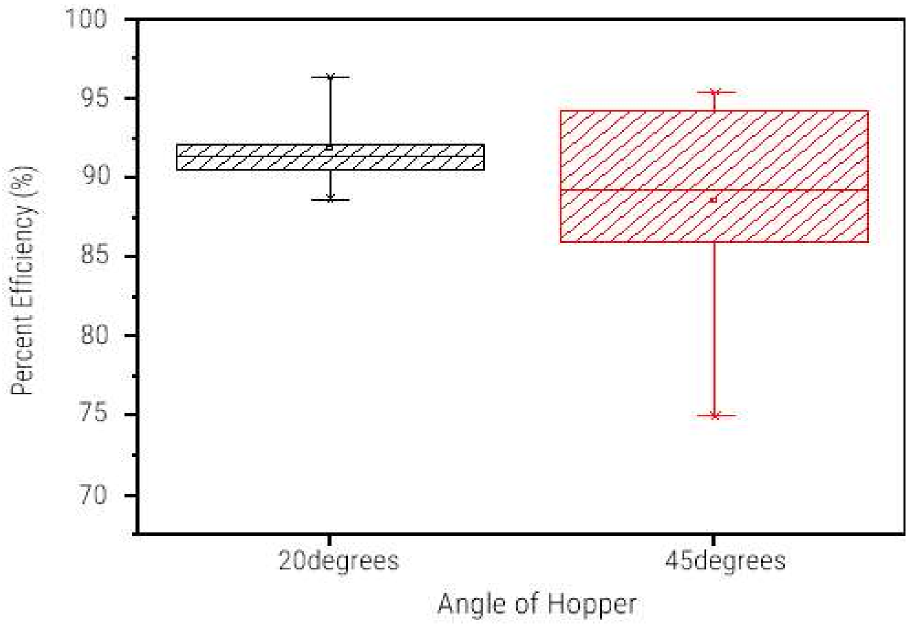

Figure 11. Percent efficiency of the machine at 20^0 and 45^0 angle of the feeding hopper

Comparative Evaluation

Comparative evaluation data of the three machines were analyzed to find their statistical differences using three substrates such as, rice straw, kakawate leaves and branches and coconut husk. The three machines were also compared according to their capacity, efficiency, cost of fuel consumed, percent decomposition of shredded materials and size distribution of the shredded materials. The machines were also compared using economic indicators such as shredding cost per hour, cost per kilogram and Break Even Cost (BEC).

Machine Capacity

Figure 12 shows the overall capacities of the three shedders. RU shedders; RU-16 and RU-14 have shown no significant difference in capacities between each other but were significantly different from the Plant Power Shedder (PPS). PPS had the lowest capacity of 382.85kg per hour, while RU-16 and RU-14 shredders have shredding capacities of 455 and 471kg per hour, respectively. The lower capacity of PPS was probably due to its small chute opening down to the shredding/chipping chamber. Unlike the two RU shedders that can accommodate large quantity of substrates and also contain nine to 10 blades that are responsible for faster chopping of the substrates.

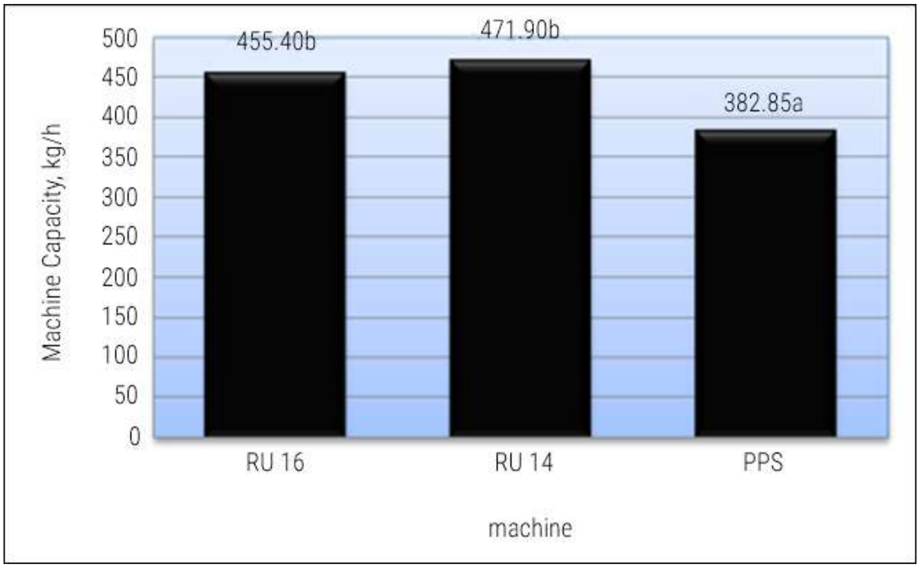

Figure 12. Overall machine capacities of the three shredders

The capacities of the three machines using three different materials are shown in Figure 13. Plant power shredder was more effective in shredding coconut husks (a), while it was lowest in shredding rice straw (b), and moderate in shredding kakawate leaves and stems (c). The utilization of both chopping and hammer blades in PPS could have contributed to its better performance in shredding coconut husk materials.

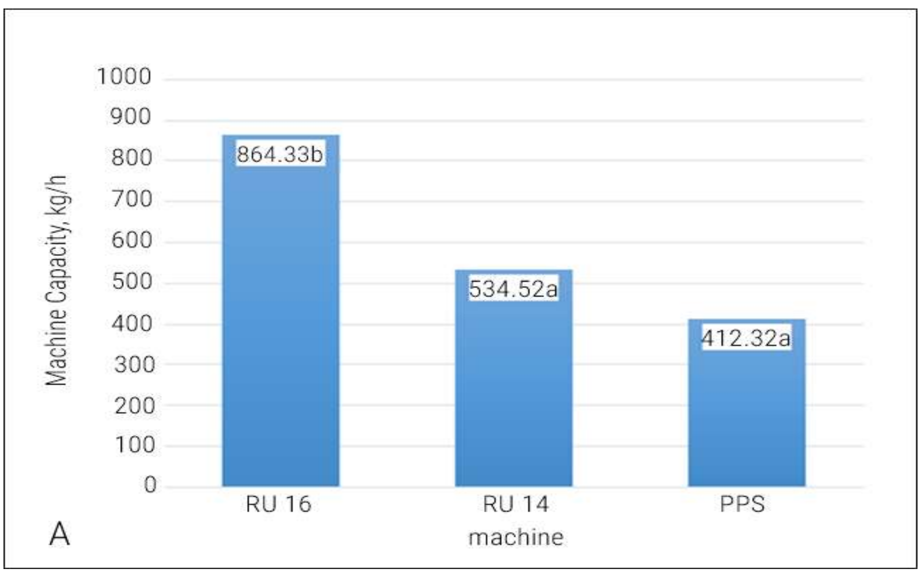

Figure 13. Machine capacities using three different materials

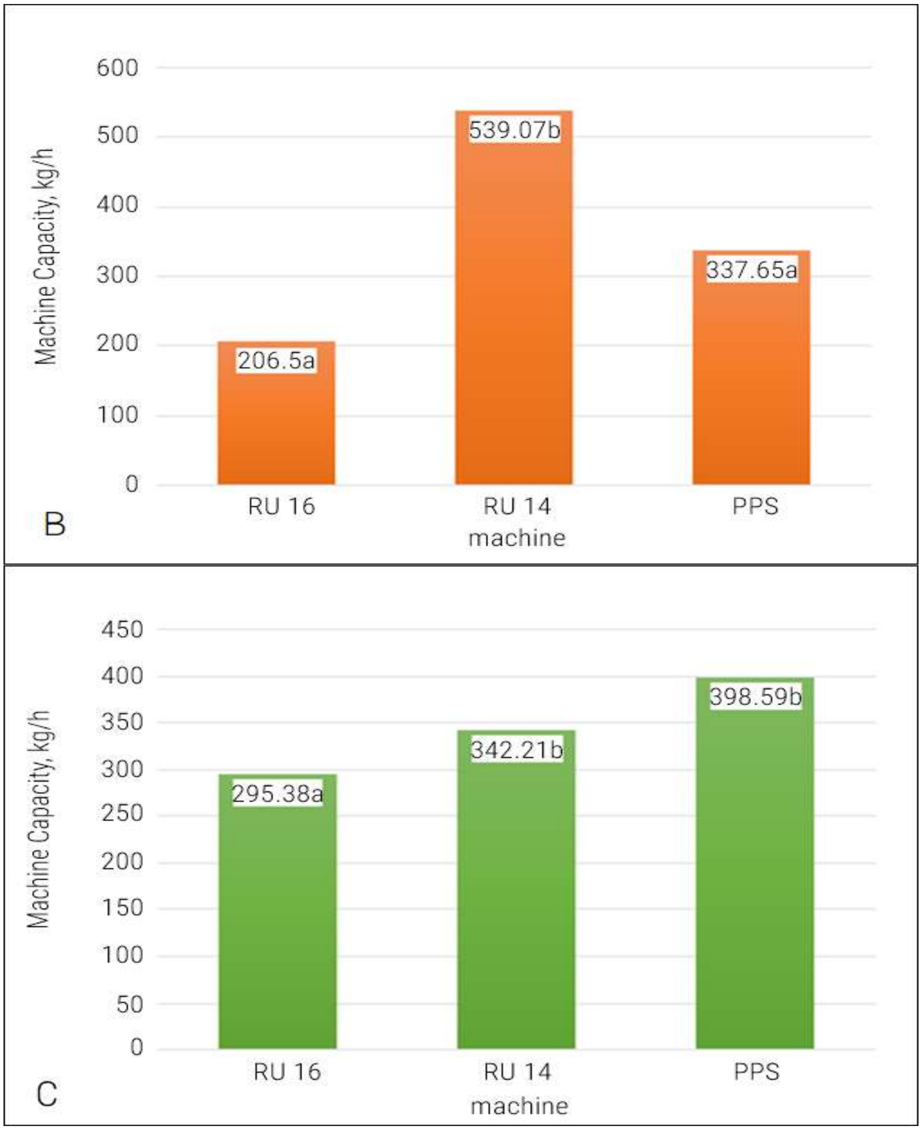

Figure 13 continued

Machine Efficiency

Overall result on efficiency based on shredding time (Jeong KY & Phillips DT 2001), shows that PPS has the highest efficiency of 95.71%, compared to RU-16 and RU-14 of 87.89% and 86.62%, respectively (Figure 14). Both RU-16 and RU-14 experienced some stuck ups which consequently lowered their efficiencies compared to PPS which has not experienced any stuck up during the evaluation.

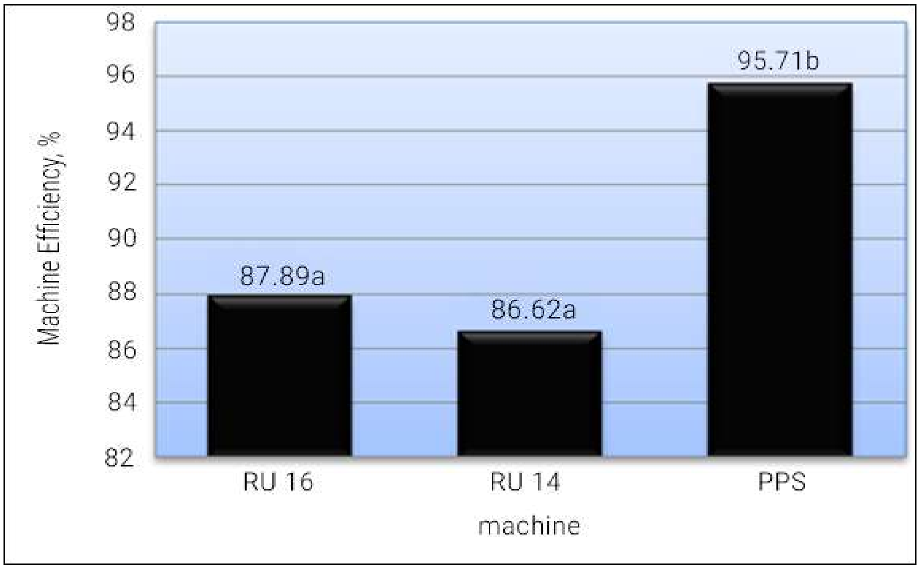

Figure 14. Overall machine efficiency of the three machines

Using rice straw as shredding material, the three shredders did not show any significant differences (Figure 15b). All the shredders achieved almost 100% efficiency. Using kakawate leaves and branches as substrate, efficiencies of the three machines were significantly different (b). RU-16 and RU-14 had efficiencies of only 66 and 62%, respectively, which are significantly different than that of PPS with 88% efficiency at 0.05 level of significance. The perpendicular direction of rotation of the chopping blades, with respect to the shredding materials in PPS, effectively chopped even branches or twigs of kakawate. Additionally, the small inlet opening in the feeding chute of PPS also limited the amount of materials to be fed in the shredding blades, giving more efficient time to shred the materials. The two RU shredders, whose feeding direction is parallel to the direction of the rotating blades, caused some materials to be caught in between the blades without cutting, which resulted to some stuck ups, thereby lowering their efficiencies. Moreover, the large opening of the feeding inlet in the RU shredders gave the operators higher tendencies to feed more materials to the shredding chamber, which resulted to some stuck-ups. Using dry coconut husk (c) as substrate material, efficiency of PPS was significantly higher than both RU shredders.

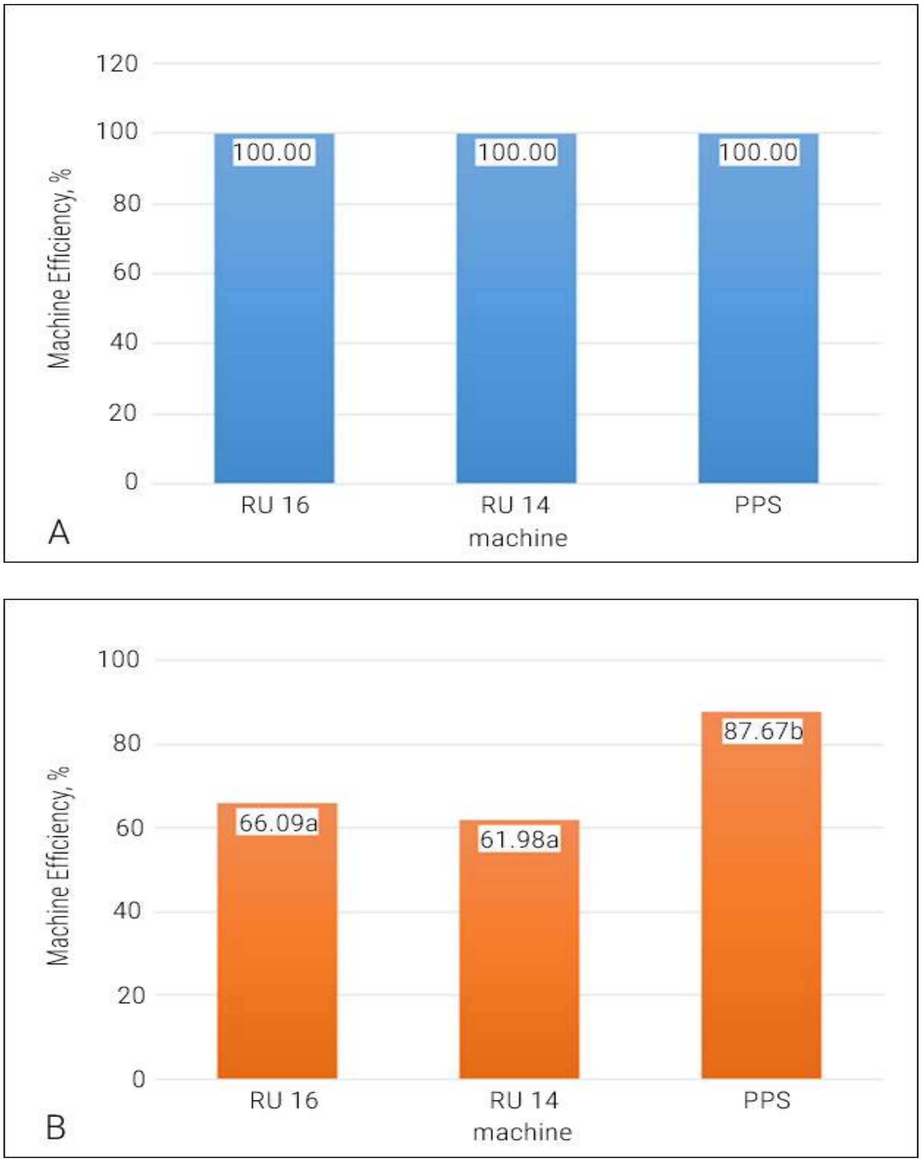

Figure 15. Detailed machine efficiency of the machine using three different materials

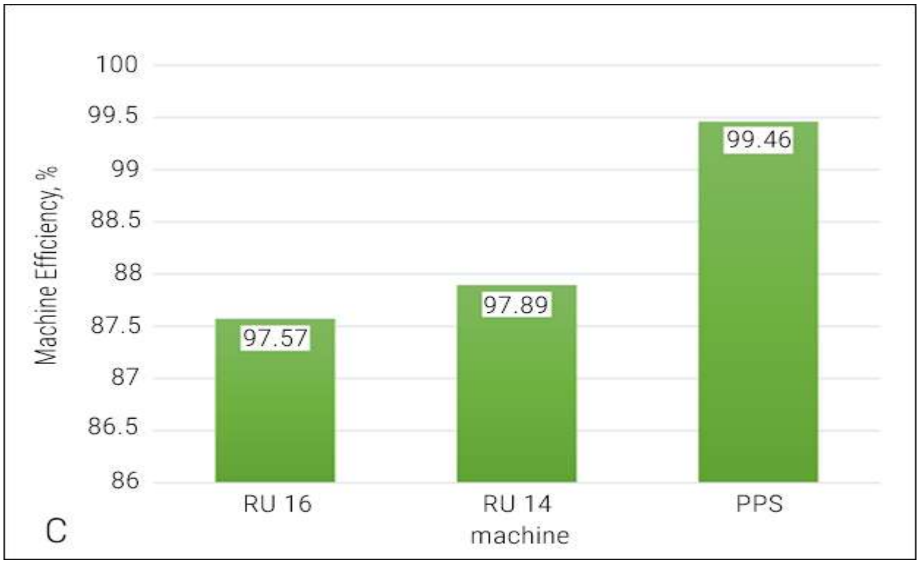

Figure 15 continued

Cost of Fuel Per Hour

Using cost of fuel consumed as basis for comparison of the three machines (Figure 16), RU-16 and RU-14 had significantly higher cost of PHP148 per hour and PHP139 per hour, respectively, than that of PPS of only PHP57.17 per hour. The presence of flywheel in PPS probably allowed the operation of the machine to run at normal throttle of the engine, thus utilizing only small amount of fuel to shred the materials. Unlike the two RU shredders (no flywheel), they have to operate at full engine throttle to effectively shred the materials, consequently utilizing more fuel during the operation.

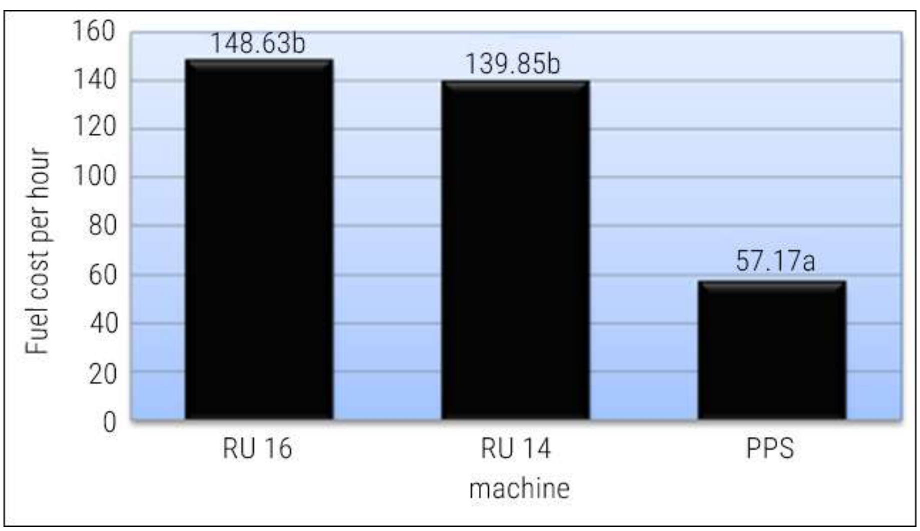

Figure 16. Cost of fuel per hour of the three shredding machines

Cost of fuel per kg

Figure 17 shows the overall results of the cost of fuel consumed per kilogram of the three shredders. PPS had the lowest cost of only PHP0.15 per kg, which is significantly different than that of RU-16 and RU-14 with costs of 0.33 and 0.31 per kg, respectively.

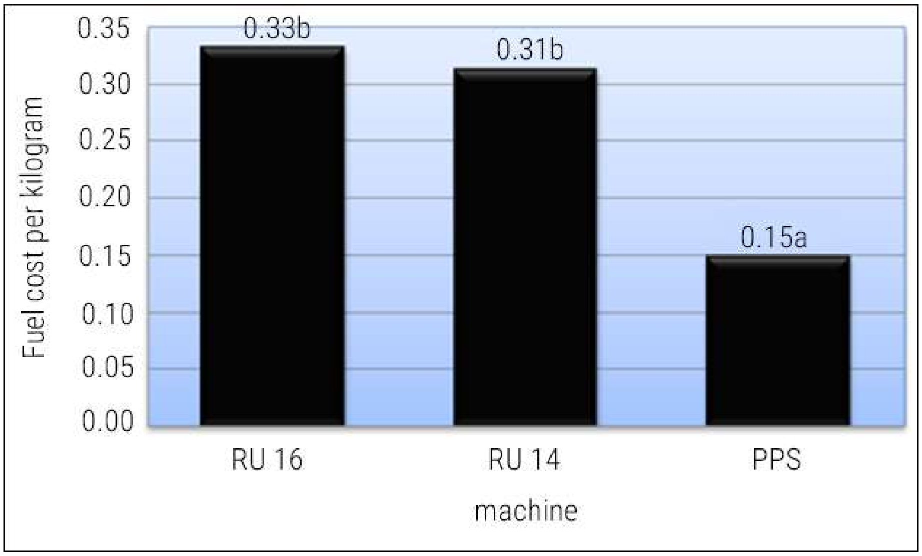

Figure 17. Cost of fuel per kg of shredded materials of the three machines

Percent Distribution and Percent Decomposition of Shredded Materials

Results of evaluation, in terms of distribution of the sizes of shredded materials using three different materials, did not show any significant differences among the three machines. Moreover, no significant difference was also observed in terms of percent decomposition of the shredded materials after 1 month and 17 days, probably because the time element of the evaluation did not reach its optimum when the materials are fully decomposed.

Break-even Cost

The ultimate way of comparing the performance of the machines is through its economic indicators, because this determines whether the machine is profitable to use or not. One of these indicators is the Break-Even-Cost, which is the sum of the fixed and variable costs of the machines. Break-even cost is the potential price of the shredded substrates that produce no loss nor profit. It was noted that for RU-16, since this was bought about 3 years ago, its price was based on its present assessed value.

Table 2 summarizes the break-even cost of the shredders. It shows that PPS has the least BEC and considered the most economical to use among the three machines. The BEC of PPS was ranging only at about PHP0.67 to PHP0.69, or an average of PHP0.68 per kg. The other two machines showed highly variable BEC, depending on the type of materials used. RU-16 is more costly to use than RU-14, maybe due to its higher purchasing cost than the latter.

Table 2. Break-even cost of the three shredders

Machine	Rice straw, Peso/kg	Kakawate leaves and branches, Peso/kg	Coconut husk, Peso/kg	Mean
RU 16	0.84	1.61	1.15	1.20
RU 14	0.47	0.96	1.23	0.89
PPS	0.67	0.69	0.67	0.68

SUMMARY

This study aimed to developing a plant shredding machine which is effective in shredding different types of plant materials such as rice straw, leaves and stems and coconut husk. The developed machine was evaluated in comparison with two other plant shredders in terms of capacity, efficiency, cost of fuel consumed per hour and per kilogram, size distribution of the shredded substrate and the break-even cost of the machine. The three shredders were evaluated using RC 216 variety of rice straw, kakawate leaves and branches and dried coconut husk. Moisture content (wet basis) of individual substrate was 76.60% for rice straw, 68.50% for kakawate and 85.04% for coconut husk. Each machine was tested using the three substrates at three replications.

Two-factor factorial Completely Randomized Design (CRD) was used in the analysis. Three operators were required to run the machines. Mean machine capacities were significantly different from each other, regardless of the materials used. These were 455.40kg per hour, 471.90kg per hour and 382.85kg per hour for RUMVD35000-16, RUMVD35000-14 and Plant Power Shredder, respectively.

Machine efficiency varied significantly among the three machines with PPS as the highest with 95.71%, followed by RU-16 and RU-14 with 87.89% and 86.62%, respectively. The Cost of Fuel Consumed per Hour of the PPS was also significantly lesser (of PHP57.17 per hour) than RU-14 (of PHP139.85 per hour) and RU-16 (of PHP148.63 per hour). PPS also had the significantly least Cost of Fuel Consumed per Kilogram of PHP0.15 per kg. RU-14 of 70.94% and PPS of 69.25% were significantly better in small-size distribution of shredded material than RU-16 with only 45.28% in small-size distribution. Percent shredded recovery was high for RU-14 of 93.97%, followed by PPS of 87.59% and RU-16 of 61.56%. The percent decomposition using rice straw and kakawate leaves and branches showed no significant differences. Among the three shredders, PPS had the least break-even cost of PHP0.68 per kg.

CONCLUSIONS

Based on the results of this study, Plant Power Shedder performed better in terms of machine efficiency, lowest fuel cost and lowest break-even cost, while RU shredder of model RUMVD35000-14 had the highest machine capacity, power to output ratio and highest percentage of short-sized shredded substrate.

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