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Research Note

Design, Fabrication, and Performance Evaluation of a Small-scale Compost-Turning Machine

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Abstract

A small-scale compost turning machine was designed, fabricated, and evaluated to speed up the decomposition rate of compost piles by giving optimum aeration through frequent turning, resulting in faster compost production. The designed compost turning machine mainly consists of thrower blades, a power transmission system, and prime mover, a side cover, a scraper, wheels, and a frame. The machine's design was created in AutoCAD software and fabricated in the metalwork shop. The performance evaluation of the machine at three different peripheral speeds [1090 rev·min^{-1}, 1276 rev·min^{-1}, and 1386 rev·min^{-1}] of the thrower blade was carried out in terms of turning capacity, turning efficiency, pulverizing efficiency, and fuel consumption. The compost turning machine operated at 1276 rev·min^{-1} optimally, and has a turning capacity of 77.35 kg·min^{-1}, a turning efficiency of 99.79%, a pulverizing efficiency of 97.21%, and fuel consumption of 2.16 L·hr^{-1}. Simple cost analysis revealed that at a custom rate of 0.17 Php·kg^{-1} of compost turned, the payback period of the investment is 172 days of turning operation. The break-even point is 33,923 kg· yr^{-1} with revenue of 75,741.12 Php·yr^{-1} compared to manual operation with a recorded capacity of 46.67 kg·min^{-1} having only revenue of Php 44,315.17 Php·year^{-1}.

Introduction

Composting turns organic or biodegradable matter, through substantial decomposition, into a helpful material called compost. Compost contains 2.5-5% Nitrogen-Phosphorus-Potassium (NPK) as described in the DA-BAFS Philippine National Standard (2013) for organic fertilizer. It is a practice in agricultural areas with a significantly high demand for compost which helps in regaining healthy soil quality (Benguet State University-Office of Extension Services, 2019).

In the Philippines, particularly in the Cordillera Administrative Region (CAR), small-scale compost production is usually practiced. Small-scale, as described by Tuladhar and Sphuler (2019), is a compost pile having at least 1-2 meters in length on each side and a height of not more than 1.5 meters, producing at least 3.375 cubic meters of compost. Composting requires the piling of substrates which are carbon-rich materials such as coco coir and sawdust, nitrogen-rich material such as chicken manure, and some greens such as shredded sunflower leaves and stems. Also, the introduction of catalysts such as probiotics and *Trichoderma* are utilized. Optionally, water is needed if the moisture content is low. After two weeks of piling, the pile is then mixed and turned to give proper aeration which help speed up and attain an odor-free decomposition. This process helps in keeping the temperature below 60ºC, because a temperature above that slows down decomposition (Kuo et al., 2004). Turning the compost is usually performed manually using shovels. The composting period can take up to 4-6 months, depending on the decomposition rate as affected by the aeration. Additionally, at the BSU-CSAC, a pulverization process is being done using a grinding machine after all of the turnings are performed because the compost fragments tend to clump up.

Manual turning of compost is laborious and time-consuming as it requires two laborers to execute the job by using a shovel. Human power is not consistent because the body gets tired in the process. As a consequence, turning is often done only once per week. Turning the compost at least twice a week decreases decomposition time, making compost production quicker. Hence, the development of compost-turning machines.

A self-propelled compost-turning machine was developed and manufactured by Morad et al. (2008) using local and inexpensive materials. The machine's performance was examined concerning variations in forward speed, rotor peripheral velocity, pile height, and frequency of compost turning per month. Their findings indicate that the machine performs best at a forward speed of approximately 1500m/h, a rotor peripheral velocity of around 240rpm, and a pile height of approximately 100cm, with the compost turned four times per month.

Another study by Suryanto et al. (2008) developed a prototype of a turning machine specifically to blend and aerate composted oil palm empty fruit bunch (EFB) cuts arranged in windrows. It features four wheels and a rotating drum with tines, allowing it to navigate through windrows standing at approximately 120cm tall by 220cm wide. The researchers were able to find that the average capacities for turning were 22,020kg/hr for EFB cuts and 25,040kg/hr for compost. At these operating conditions, the machine achieved average forward speeds of 104.4m/hr for EFB cuts and 75.0m/hr for compost.

In a study by Sayed et al. (2021), they were able to develop a compost-turning machine (CTM) suitable for small-scale farms. The turning machine utilized in their experiments was derived from a self-propelled harvesting device compatible with small-scale agricultural operations. In their study, to achieve optimal compost quality and expedite the maturation process, the researchers recommended operating the CTM at a peripheral velocity of 540rpm, and a forward speed of 2.76km/h, with compost turned every 7 days, and using the I-shaped blade.

Although the machines presented are available, importing them is costly. Additionally, these machines are not fit for the needs of the potential users in our locality because they require a larger space. After interviewing local compost producers at BSU-CSAC, the researchers were able to identify what needs to be considered in developing a compost-turning machine suitable for their facility. This study, then, aimed to develop a small-scale compost-turning machine.

Specifically, this study aims to (1) develop a small-scale compost turning machine, (2) evaluate the machine by assessing its turning capacity, turning efficiency, pulverizing efficiency, and fuel consumption, with a focus on how these parameters are affected by the speed of the thrower blade, and (3) determine the economic benefits of the compost turning machine by conducting a simple cost analysis of the machine taking into consideration the cost per ton of compost turned versus manual turning.

Materials and Methods

Design of the Machine

There is no existing compost turner available in the local market so the design of the compost-turning machine has considered the small-scale composting facility of farmers in CAR. It was also a simple design for easy fabrication and operation so that farmers could efficiently utilize and adapt the machine. Locally available materials were also considered in the design for easy maintenance and repair of the farmers. The machine components are thrower blades, power transmission mechanism, prime mover, side cover, scraper, wheels, and frame. Figure 1 illustrates the design of the small-scale compost-turning machine.

Figure 1

Design of the Small-Scale Compost-Turning Machine

Description of the Major Components of the Compost-Turning Machine

Thrower Blades

These are made of leaf springs tilted at 15º with a hook welded on the tip. The blades have a length of 29.21cm and a width of 5.715cm while the hook has a dimension of 5.08 x 6.35cm. The blades are welded to a mild steel shaft going to the power transmission mechanism.

Power Transmission Mechanism and Prime Mover

The power transmission mechanism consists of pulleys and a V-belt to transmit the rotary power of the prime mover to the throwing blade. The prime mover is a 6.5hp gasoline engine that provides power to the machine.

Side Cover

This is made out of a rubber mat with a frame made of a flat bar.

Frame

This is a part of the device where all the other parts were mounted by bolts, nuts and rivets. It supports all other parts of the machine.

Scraper

The scraper is made out of a flat sheet with a dimension of 45.72cm x 10.16cm folded to a 90° angle.

Wheels

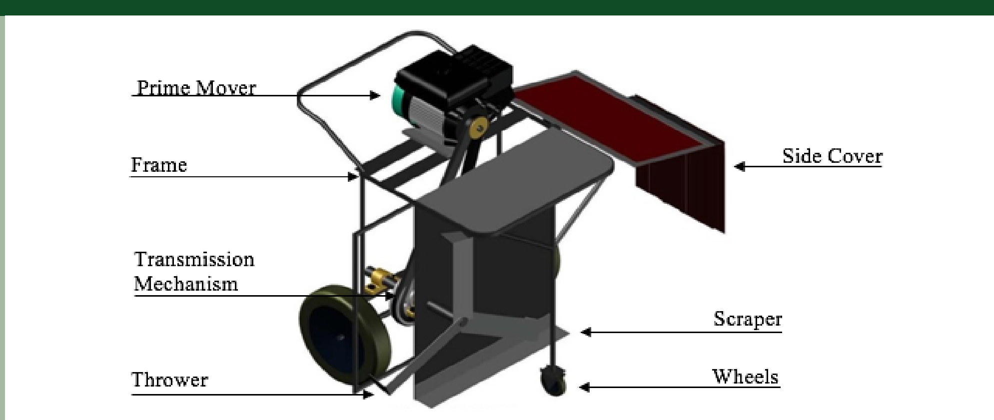
The wheels at the rear part of the machine are heavy-duty rubber wheels while the single wheel in the front is a 360° turning caster made of nylon.

Fabrication of the Compost-turning Machine

The compost-turning machine was fabricated

Figure 2

Parts of the Compost-Turning Machine



and assembled in the metalwork shop of the College of Engineering. The frame (78.74cm x 114.3cm x 91.44cm) was built from a 1.91cm diameter galvanized iron (G.I.) pipe to mount the other components of the machine. The diameter of the thrower blades is 29.21cm and the hooks on the tip of the blades are 5.08cm x 6.35cm. The thrower blades are welded to a shaft attached to a pulley. The pulley is connected to the 6.5hp gasoline engine through the V-belt. The fabricated compost-turning machine is shown in Figure 3.

Principle of Operation of the Machine

The operation of the machine begins with the starting of the gasoline engine. The operator holds the frame's handle and positions the machine at one end of the compost pile. As the operator moves forward, pushing the machine towards the pile, the spinning thrower blades penetrate and cut the compacted compost pile and then throw it on the other side of the pile (left side of the operator) as shown in Figure 4.

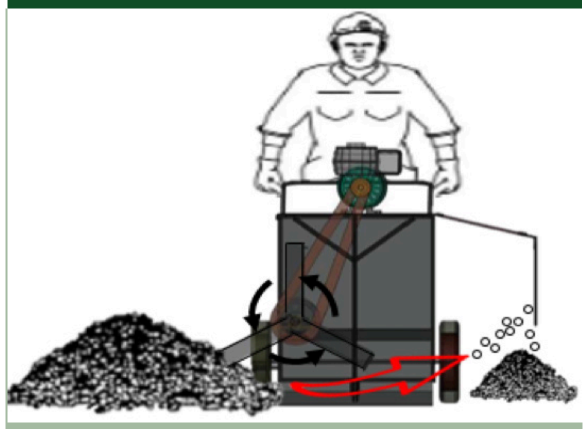
The side cover minimizes the scattering of the compost during turning and directs all the compost to the side. As the compost pile is cut and thrown by the blades it is also simultaneously pulverized. The remaining compost on the ground not reached by the blades is scraped by the scraper. After reaching the other end of the compost pile, the operator moves backward to the starting position and then adjusts the machine to turn the remaining compost pile.

Figure 3

The Actual Fabricated Small-Scale Compost-Turning Machine

Figure 4

Principle of Operation of the Machine



Preparation of Test Materials

A compost pile consisting of a mixture of sawdust, coco coir, and manure was prepared for the performance test of the machine. The compost pile is already in the third stage of turning. Thus it is at 30% moisture content. It has a volume of 4.78 cubic meters, (3.66m x 2.14m x 0.61m) prepared in a compost pen with an area of 3.66m x 3.66m. It was arranged so that a 1.52m space between the compost pile and the compost pen wall is provided for the turning of compost. The setup is shown in Figure 5.

Figure 5

Test Set-up of the Compost Pile

Data Gathered

The data gathered in the evaluation of the study include the: weight of compost turned (kg) which is weighed right after every minute of turning by collecting them and putting them in sacks; the weight of scattered loss (g) which is the compost particles that were thrown outside the perimeter of the compost quadrangle, trapped using a wide plastic sheet; the weight of unpulverized compost (g) which are compost particles that were left during the sieving process. The sieve used was a wire mesh having a 3cm by 3cm spacing dimension, and the amount of fuel consumed (L) was recorded by measuring the decrease in fuel level in the fuel tank immediately after each operation. It was done using a graduated cylinder to measure the amount needed to fill the tank up to the bottom of the filter. These data were used in the performance evaluation of the compost-turning machine.

Performance Evaluation Parameters

The machine performance test was conducted to evaluate the performance of the compost-turning machine as affected by the peripheral speed of the thrower [1090 $rev \cdot min^{-1}$, 1276 $rev \cdot min^{-1}$, and 1386 $rev \cdot min^{-1}$]. The performance parameters evaluated are the: turning capacity which refers to the total amount of materials including the scattered compost turned over the total time of operation, which is 1 minute, expressed in kilograms per minute; turning efficiency which is the ratio between the difference of the mass of the turned compost and the mass of the scattered loss to the total mass of the turned compost, expressed in percentage; pulverizing efficiency which refers to the ratio between the acceptable pulverized compost to the total sample taken which was 10,000 grams, expressed in percentage; and fuel consumption which is the total amount of fuel consumed over the total time of operation, starting from when the engine was turned on until it was turned off, expressed in liters per hour. Three replications were performed for each level of the peripheral speed. The performance test was carried out for one minute for every replication. There are a total of 9 compost plots used in the performance test.

Turning Capacity

The turning capacity (CT), expressed in kilogram per minute ($kg \cdot min^{-1}$), was calculated by dividing the mass of the turned compost by the operating time as shown in Equation (1).

$$C_T = M_T / t \qquad (1)$$

where: C_T = turning capacity (kg/min);
M_T = mass of the turned compost (kg);
t = operating time (in minutes)

Pulverizing Efficiency

The pulverizing efficiency (P*eff*) (%) was determined as the ratio between the mass of the acceptable pulverized compost to the mass of the sample (10,000 grams) randomly taken at the turned compost, as shown in Equation (2).

$$Peff = \frac{(10000 - Mup)}{10000} \times 100 \qquad (2)$$

where: P*eff* = pulverizing efficiency (%);
M*up* = mass of unpulverized compost (g)

Turning Efficiency

The turning efficiency (T*eff*), of the machine, is the ratio between the difference of the mass of the turned compost and the mass of the scattered loss to the total mass of the turned compost, expressed in percentage (%) as shown in Equation (3).

$$Teff = \frac{(M_{TC} - M_{SL})}{M_{TC}} \times 100 \qquad (3)$$

where: T*eff* = turning efficiency;
M_{TC} = the mass of turned compost;
M_{SL} = mass of scattered loss

Fuel Consumption Rate

It refers to the total amount of fuel consumed over the total operation time, starting from when the engine was turned on until it was turned off, expressed in liters per hour. The amount of fuel consumed was determined by measuring the decrease in fuel level in the fuel tank immediately after each operation. It was done using a graduated cylinder to measure the amount needed to fill the tank up to the bottom of the filter.

$$FR = Fc / t \qquad (4)$$

where: FR = fuel consumption rate (L/hr);
Fc = amount of fuel consumed (L);
t = time of operation (h);

Simple Cost Analysis

The economic analysis of the compost turning machine performed includes the fixed cost; variable cost; payback period; and break-even point.

Fixed Cost. The fixed cost (FC) was calculated by the parameters given in Equation (5).

$$FC = D + I + T \quad (5)$$

where: FC = fixed cost;
D = depreciation cost;
I = interest on investment;
T = tax and insurance

Variable Cost. The variable cost (VC) was calculated by the parameters given in Equation (6).

$$VC = L + R + F \quad (6)$$

where: VC = variable cost;
L = labor cost;
R = repair and maintenance;
F = fuel cost

Net Income. The net income (N) is the income incurred by the difference of Total Revenue and the Annual Operating Cost. This is calculated using the formula given in Equation (7).

$$N = TR - (F = V) \quad (7)$$

where: TR = Total revenue;
F = Fixed cost;
V = Variable Cost

Payback Period. The payback period (PP) is the time of the machine utilization to return the payment of its investment. This is calculated using the formula given in Equation (8).

$$PP = C_i / N \quad (8)$$

where: PP = payback period;
C_i = initial cost;
N = net income

Custom Rate. For the custom rate (CR), the following were considered: Php350 per day (DOLE, 2022), similar to the standard salary for a laborer, and 2,100kg per day as the amount of compost turned in the compost facility. Thus, the machine has a customs rate of 0.17 Php/kg.

Break-even Point. The break-even point (BEP) was calculated using the formula given in Equation (9).

$$BEP = FC/(CR \times VC/C) \quad (9)$$

where: BEP = break-even point;
FC = fixed cost (Php.);
CR = custom rate (Php/kg);
VC = variable cost (Php);
C = capacity (kg/min)

The performance evaluation was based on PNS-BAFS-PAES-248:2018, Multi-crop Pulverizer, and PNS-BAFS-PAES-216:2014, Hammer Mill. No other similar machines are available in PAES so some formulas were revised for the turning capacity and efficiency (DA-BAFS, 2018).

Statistical Analysis

The data gathered in the experiment were analyzed using Complete Randomized Design (CRD). The factor considered was the peripheral speed of the thrower blade at three levels [1090 rev·min^{-1}, 1276 rev·min^{-1}, and 1386 rev·min^{-1}]. Analysis of variance (ANOVA) was used at a $p<0.05$ level of significance. The difference among the means was tested by Tukey's Honest Significant Difference (HSD) using the IBM-SPSS Software.

Results and Discussion

A compost-turning machine was designed for a small-scale composting facility within the purchase range (Php20,000-30,000) of the farmers. The machine components were designed using AutoCAD software (version 2015). It was fabricated with locally available materials in the region for easy repair and maintenance. Further analysis of the machine's performance parameters and cost analysis is discussed in the succeeding sections.

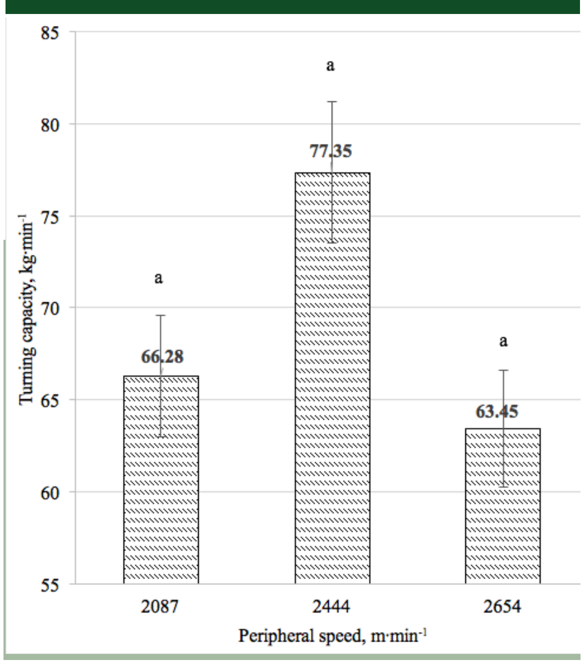
Performance of the Machine

Turning Capacity

The result of the analysis shown in Figure 6 reveals that the turning capacity of the machine is not significantly different as affected by the peripheral speed of the thrower blades. The highest turning capacity was observed for the speed of 1276 rev·min^{-1} with 77.35 kg·min^{-1}. However, capacity declined to 63.45 kg·min^{-1} with a higher peripheral speed (1386 rev·min^{-1}) even with the same engine (6.5hp) used in the design available in the purchase range of small-scale farmers. This result is supported by the statement of Dotson (2018) that a smaller pulley can produce a higher speed while a larger pulley results in a slower speed. However, when it comes to the shaft power, a larger pulley has more force than a smaller pulley. This is because a smaller pulley having a high speed has a shorter time to penetrate and get more force to turn the compost pile resulting in a low amount of compost to be turned. In comparison, a larger pulley having a lower speed enables the blade to penetrate a longer period compost pile taking a lot of force to turn the compost on the other side.

Figure 6

Turning Capacity as Affected by Peripheral Speed

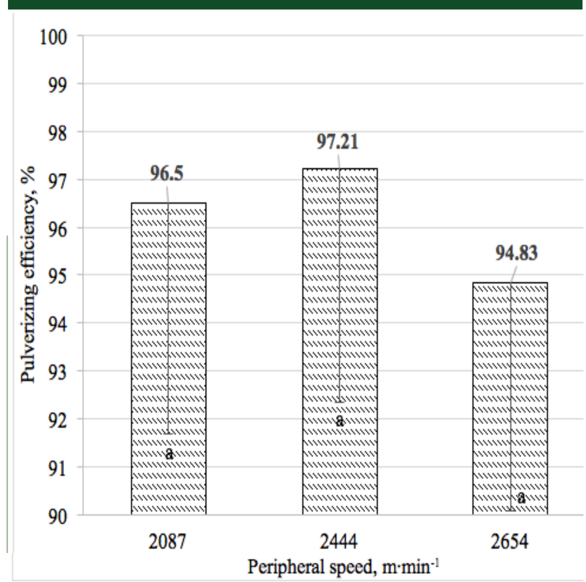


Pulverizing Efficiency

Figure 7 shows the result of the analysis of the pulverizing efficiency of the compost-turning machine as affected by the peripheral speed of the thrower blades. The highest mean pulverizing efficiency of 97.21% (1276 rev·min^{-1}) is not significantly different from the other observed pulverizing efficiency. The trend of the result is explained by the less power transmitted on the shaft as the peripheral speed increases as discussed by Dotson (2018).

Figure 7

Pulverizing Efficiency as Affected by Peripheral Speed



Turning Efficiency

Figure 8 shows the turning efficiency of the compost-turning machine as affected by the peripheral speed of the thrower blades. The result reveals a significant difference in turning efficiency among the treatments. The highest mean turning efficiency (99.79%) was observed for 1276 rev.min^{-1} and 1386 rev·min^{-1} peripheral speed. This result shows that the designed and fabricated machine can efficiently turn compost piles.

Fuel Consumption

The result of the analysis shown in Figure 9 reveals that the fuel consumption of the machine is significantly different as affected by the

Figure 8

Turning Efficiency as Affected by Peripheral Speed

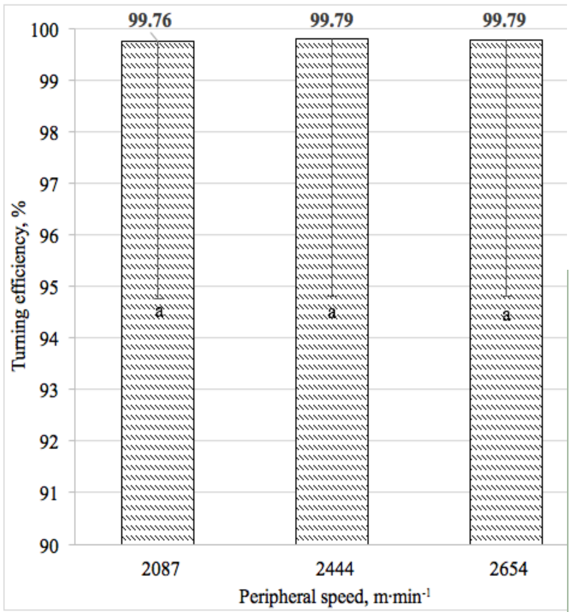
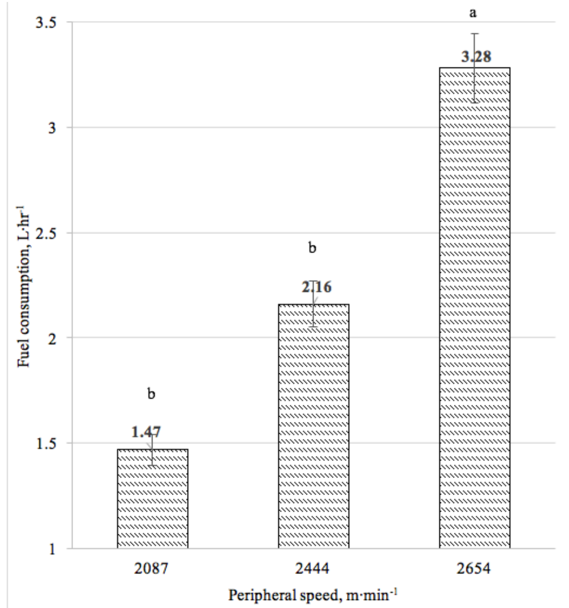


Figure 9

Fuel Consumption as Affected by Peripheral Speed



peripheral speed of the thrower blades. As the peripheral speed of the machine increases, fuel consumption increases. The lowest fuel consumption of 1.47 L·hr^{-1} observed on the lowest peripheral speed is not significantly different from 2.16 L·hr^{-1} (1276 rev·min^{-1}). The result is in agreement with the study of Abdel–Mottaleb (2008) and Dominguez (2021) which showed that as the peripheral (tip) speed of the blade increases, fuel consumption or energy consumption increases.

Cost Analysis on the Use of the Machine

The machine was designed considering the purchase capability of farmers. The cost of fabricating the machine was Php24,120.00 and the labor cost of the operator was 350 Php·day-1 (Department of Labor and Employment–Cordillera Administrative Region, 2022). The result of the analysis is given in Table 1.

The payback period of the investment is 172 days or estimated to be nearly half a year which is a good deal for the farmers. The break-even curve chart illustrated in Figure 10 shows that at 0.17 Php·kg^{-1} custom rate, the machine must process 33,923 kg·yr^{-1} of compost. Increasing beyond this point creates an income opportunity for the farmer.

Table 1

Simple Cost Analysis of the Compost-Turning Machine

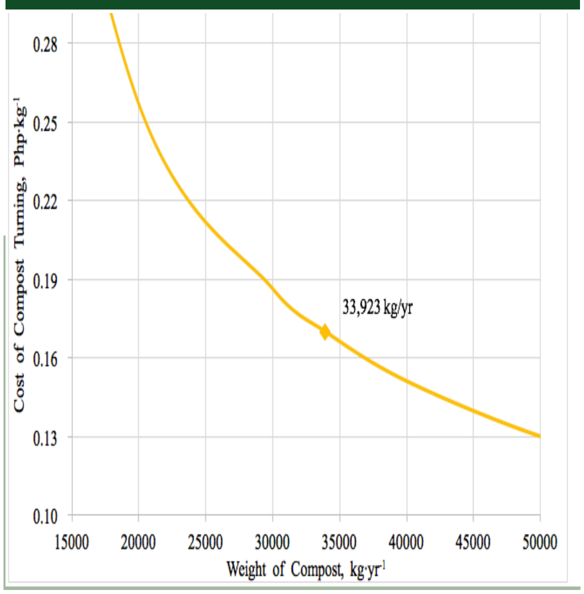
BASIC ASSUMPTIONS	
Initial Cost	Php 24,120
Salvage Value	10% of Initial Cost
Estimated life, n	10 years
Interest	10%
Tax, Insurance	3%
Repair and Maintenance	10%
Average Fuel Cost	Php 74.60 (as of April 11, 2020)
Fuel Consumption Rate	2.16 L/hr
Fuel Cost per Hour	Php 161.14
Operation per day	1 hour
Annual Use	4 days or 96 hours
Salary per day	Php 350
No. of operator	1
Custom Rate	Php 0.17/kg
Turning Capacity	77.35 kg/min.

Table 1 *Continuation...*

Economic Parameter	Analysis Result	Remarks
Fixed cost	4,221 Php·yr^{-1}	Php350
Variable cost	211.49 Php·hr^{-1}	Operator fee is 43.75 Php (based on 350 Php·day^{-1}) at 1 hour of operation per day and 96 days of annual use
Payback period	0.47 years or 172 days	Calculated based on the initial cost
Break-even point	33,923 kg·yr^{-1}	Calculated based on the custom rate of 0.17 Php·kg^{-1}

Figure 10

Break-Even Curve Chart



Conclusions

The Small-scale Compost Turning Machine was designed and fabricated with an overall height of 78.74cm, length of 114.3cm, and width of 91.44cm. It comprises 5 main parts namely: thrower, frame, prime mover, scraper, and cover. The best operating speed is 2444 meters per minute having a turning capacity of 77.35 kg/min, a turning efficiency of 99.79%, and a pulverizing efficiency of 97.21%. The machine vs. manual turning comparison showed that manual turning using a shovel has a capacity is 46.67 kg/min, a turning efficiency of 100%, and a pulverizing efficiency of 84.84%. The computed cost of fabricating the machine was Php24,120.00. The annual use was assumed to be 4 days, or 96 hours, with a custom rate of Php0.17/day. Given these assumptions, the computed revenue is Php75,741.12/year. With an annual operating cost of Php23,501.56/year, the net income is Php52,239.56/year. The calculated payback period is 0.46 years, with a return on investment up to 222.28%. Lastly, the break-even point calculated is 33,304.69kg. Further analyses of this machine can be conducted to a higher moisture content of the compost pile.

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