Abstract: The increasing utilization of rice combine harvesters in the Philippines has made collection of scattered rice straw difficult and laborious. While there are high demands for using rice straw, e.g., for feed or mushroom production, rice straw is predominantly burned in the field due to labor shortages and the high manual cost of collection, particularly for scattered rice straw harvested by combine harvesters. This study conducted an assessment and evaluated the feasibility of mechanized collection of rice straw by comparing the performance of two types of baler (i.e., roller and piston type) for two seasons—2019 wet and dry seasons at the International Rice Research Institute (IRRI) and in Nueva Ecija, the Philippines. The study collected data on fuel consumption, manpower requirements, and field capacity by operating the balers to collect scattered rice straw in the field and piled rice straw that was left in the field after threshing. The round baler operated at 35% lower effective field capacity (EFC) on piled rice straw than on scattered rice straw, while the square baler operated at 2.33 times and 5.79 times higher EFC compared with the round baler on piled and scattered rice straw, respectively. The square baler used for collecting scattered rice straw is more appropriate under Philippine conditions, with a significantly lower baling cost by about 68% and an average EFC that is 4.43 times higher compared to the round baler. With the increasing demand for rice straw as feedstock for ruminants and for other alternative uses, using mechanical balers to gather scattered rice straw in the field is a sustainable option for farmers to utilize the straw for value-adding purposes. This is a foremost study conducted in the Philippines to guide policy makers, development workers, and end-users on the suitability of either square balers or round balers to gather scattered rice straw in the field after rice harvesting with combines.

Keywords: rice straw; combine harvesting; mechanized collection; balers; effective field capacity; business models

1. Introduction

Every ton of reaped rice yields about 1.35 tons of rice straw [1–3], and because rice is a staple food in most countries, rapid elimination of this agricultural waste from the field has long been a problem, especially with the advent of combine harvesters where the rice straws are scattered in the field after harvesting operations. The use of combine harvesters has become popular because it lessens harvesting time and reduces the risk of exposure of the crops to harsh weather conditions by combining all five harvesting operations, these being cutting, collecting, and threshing the rice crop, and separating and
cleaning the grains [4,5]. This reduces the labor requirement and postharvest losses and enhances the quality of the harvested rice [4,6]. In some parts of Asia, rice is harvested with partly mechanized methods using either manual methods or a mechanical reaper for cutting, and then using the axial flow thresher that was developed by the International Rice Research Institute (IRRI) in the 1970s for separating the grains [4]. According to [7], the method of harvesting dictates the state of the rice straw in the field, whether spread or piled, as well as the ease of collection.

Communities that use combine harvesters, however, in the absence of options for mechanized rice straw collection, tend to resort to in situ burning because it is the most convenient, cheapest, and fastest way to eliminate rice straw to clear the land for the next crop [5,8]. This can be attributed to the increased amount of rice straws that are loosely scattered and left in the field, which makes manual collection difficult [9]. There is an increased in the amount of rice straws loosely scattered in the field because of the increasing use of combine harvesters in harvesting rice in the Philippines, where rice straws are dispelled out of the combine machine in loose form which are hard to collect manually. On a global scale, the rate at which rice straw is produced yearly is about 445–731 million tons [7,9], and around 60 million tons of this is still being burned every year. In the Philippines, where about 18 million tons of rice straw is produced annually, the practice of rice straw burning was particularly high at 95%, as reported by [10]. A recent survey to assess rice straw management options in major rice growing areas in the Philippines showed that, as a result of government support for rice straw incorporation, field burning of rice straw has been significantly reduced to 27%, about 54% is incorporated in the field during land preparation, and around 19% is gathered from the field for alternative uses [11]. In Central Luzon, the Philippines, the average annual production of rice straw is about 1.6 M tons, and 47% of this is contributed by the province of Nueva Ecija, which is recognized as the rice granary of the Philippines with an average yield of 4.2 tons per hectare [12–14]. A study conducted by [13] revealed that only 57% of the available rice straw is used to cater to the demand of the end-users for animal feed, mulching material, and as substrate for mushroom production. There is still a large amount of rice straw left in the field, wherein burning is the main disposal practice [13].

The practice of open field burning of rice straw has many deleterious effects on the economy and the environment, such as the opportunity loss of utilizing rice straw in potentially useful applications such as conversion to biofuel, increased air pollution, and degradation of soil quality via loss of minerals [15–17]. Better management methods are therefore warranted to mitigate these. In the Philippines, there are local ordinances that ban the in-field burning of rice straw, that is why end-users and farmers must be provided with alternatives or sustainable technologies that can use rice straw for extra income. This study aims to disseminate knowledge in the sustainable use of rice straw after combine harvesting by employing an effective and efficient collection method using the rice straw baler.

Rice straw can also be used as feed substitute for ruminants; although poor in quality and low in protein content, its quality and nutrient contents can be improved by supplementation with protein, energy, and/or minerals, and via the use of enzymes combined with chemical pre-treatments to maximize utilization of rice straw and increase intake [18]. Allen, et al. (2020) also mentioned that rice straw can be converted to biochar that essentially stabilizes carbon (C), and when rice straw is used for biochar, [19] cited that its properties of alkalinity, cation exchange capacity, and high levels of available phosphorus and extractable cation would indicate its potential application as a fertilizer and soil amendment which can deliver a variety of sustainability outcomes, including carbon sequestration, improved soil fertility, mitigation of off-site effects from agrochemicals and renewable energy [20].

Another mitigation strategy identified by [15] includes mechanized straw collection. Collecting rice straw in the field can contribute to the reduction of greenhouse gas emission (GHGE) and hastens land preparation [15]. Rice straw, when collected from the field, can be used for other purposes, such as the generation of bio-energy and utilization as a growing substrate for mushrooms [7]. Agricultural crop residues have great potential as cellulosic biofuels and are fast becoming the most environmentally attractive and technologically feasible alternative to oil [21], and residues such as rice straw can be used to generate fuel, heat, or electricity through thermal, chemical, or bioprocesses [22]. Rice straw can also
help improve soil nutrition and fertility when incorporated back into the soil [16,21,23]. There are many off-field uses of rice straw to drive the impetus of collecting this residue in the field, but the challenge lies in how to effectively and efficiently collect it in the field.

Manual collection of rice straw spread out by combine harvesters is difficult, but mechanical collection, through the use of a rice straw baler, eases the task, as well as lessens the time consumed to complete it. Mechanized collection of rice straw involves three main operations—picking up of straw materials, compacting it into bales, and transporting them to the bund or the side of the field. In some cases, loose rice straw is piled beside the house of farmers or at the side of the field and is then used as feedstock for cattle, buffalo, and other ruminants. In mechanized systems, the loose straw is collected straight from the field and compacted into round or square shapes with the use of baling machines for easy handling and transport. Baling, a popular mechanized method of collecting hay, straw, and other fibrous materials that undergo the densification process, is an efficient method of removal of material from the field and provides ease in transportation and manipulation of bales, solves the problem of shortage, and offers flexibility in storage [2,24,25]. The rice straw balers used in the study are the roller type (round) and piston-type (square) balers. One advantage of the roller-type baler is that it can compress collected loose straw by 50–100% density through a series of roller mechanism that form the cylindrical or round bales which can significantly reduce handling and transportation costs, which is similar with the piston-type baler with the compressing advantage. One downside of the roller-type baler is that it cannot work continuously in the field as the operation must stop periodically during tying and unloading of the bales. On the other hand, the piston-type or square baler can be operated continuously without needing to stop when bales are unloaded [26]. The wider and longer dimension of the square baler with the tractor pulling it is a disadvantage when maneuvering through narrow farm roads in certain locations in the Philippines. Mechanized rice straw collection, like any other mechanical process, requires capital investment. A small round baler made in Japan that uses an electromechanical twine threading system to collect dried straw costs about US$8500 [27]. In Brazil, a large round and square baler for processing sugarcane straw (bale weight of 381 kg round and 294 kg square) would require an investment of US$80,585 and US$146,341, respectively [25]. Capital investment is also needed for an appropriately sized-tractor to pull the baler. Additional costs for operating the baler would include the twine, fuel, lubricants, and oil. An economic analysis conducted in Vietnam indicated that this small round baler could be operated at a cost of US$19.0 per ton of straw, and the investment cost could be recovered in 2.1 years at an internal rate of return (IRR) of 38%, assuming an annual operation of 40 days [27].

Some rice straws are left in piles in the field when harvesting is done manually, and the crop is threshed with stationary threshers. Collecting the straw in piled condition is different compared to when it is loosely scattered in the field. These two different scenarios of collecting rice straws in the field often have different effects on fuel consumption, field capacity, time, and other factors.

Traditional rice straw collection with manual labor is an arduous task in the field and is becoming rare and costly and therefore necessitates the use of machinery to optimize operation, reduce costs, and postharvest losses [24,28]. The Philippines’ case in particular, with the aging farmer population and the growing exodus of the younger generations going to work in urban areas, requires mechanized options. The need to collect rice straw for alternative uses such as feed substitute for ruminant is a great opportunity to address food security and provide alternative income to farmers. Without depending on scarce labor and high capital investment for machinery, there is a viable alternative for optimizing operations of gathering rice straw left in the field, which is via a custom hire service, which has been proven to be a contribution to sustainable farming that is beneficial to both the contractors and the customers [29]. Looking from another perspective, there is the concept of shared equipment, which is viewed as an effective way of coping with high equipment costs and the lack of funds to acquire machinery, despite the fact that there are numerous problems attached to this kind of arrangement [30].

This is a pioneering study in the Philippines on mechanized straw collection that followed the study conducted by Launio et al. that looked at the logistics of collecting rice straw for power generation.
in Nueva Ecija [13]. The study took stock on the different options of sustainably using rice straw that starts from collection in the field for alternative uses and contribute to farmers’ income. This study will look specifically at the economic benefits of using rice straw balers to gather the straw and will increase understanding on balers that are suitable under Philippine conditions. This study will fill some knowledge gaps as there is no current study on mechanized rice straw collection specific to the situation in the Philippines.

2. Materials and Methods

2.1. Experimental Design and Machines Used

Field trials on mechanized straw collection at the IRRI Zeigler Experiment Station (ZES) (14.148° N, 121.267° E) during the dry and wet seasons of 2019 using two kinds of balers (as treatments, i.e., round and square balers) were implemented in a completely randomized design in harvested plots with an area of 2500 m². There were two conditions of rice straw considered after harvest—scattered rice straw after harvesting with combines, and piled rice straw after harvesting manually and threshing with a stationary thresher.

The square baler used was a CLAAS Markant 55 that uses a piston to compress rice straws in the compaction chamber. It has a pick-up width of 1.65 m and is attached to the drawbar hitch of a tractor, where it is pulled from behind and derives power from the Power-Take-Off (PTO). This baler can operate continuously without needing to stop when unloading the bales. The round baler used was a STAR MRB 0850B that uses sets of rollers to compress rice straws inside the baling chamber. The power for baling is delivered through the PTO of the tractor, and the bale expeller consists of a built-in, independent hydraulic mechanism. This baler has to stop periodically for tying the bales and during unloading. The baler is connected through a three-point linkage with the hydraulic system for controlling the pick-up height [26].

The square baler was pulled by a 60HP four-wheel drive (4WD) tractor, and the round baler used a 35HP 4WD tractor (Figure 1) to pull it from behind to gather rice straws scattered on the field after combine harvesting and rice straws that had been piled on the field. The experiment was conducted for two seasons in 2019 (wet and dry seasons) and was replicated three times for each baling operation to collect two sets of data, which included (a) technical operation parameters of a round and square baler that include field capacity, operating time, and amount of rice straw baled; and (b) relevant data for assessing financial and economic feasibility of rice straw balers, such as fuel consumption, manpower requirement, twine, interest rate, maintenance, and depreciation.

![Figure 1](image_url)

Figure 1. The three balers evaluated in the study: (a) STAR MRB 0850B; (b) CLAAS Markant 55; and (c) New Holland BC5070.

We included a study in Nueva Ecija (15.229° N, 120.877° E) following the same experimental design (i.e., Completely Randomized Design) to evaluate the operations of a New Holland BC5070 square baler in collecting rice straws scattered in the field. The operation of this baler is similar to the CLAAS Markant 55, but has a wider pick-up width of 2 m. The baler is pulled by a 90HP 4WD...
tractor during field operations and is connected to the drawbar hitch and the hydraulic system, and it derives power from the PTO. The field trial was conducted in two locations in 2019 during the dry and wet seasons. Similar parameters of field capacity, operating time, fuel consumption, manpower requirement, and other related cost of operations were gathered in the field.

2.2. Data Collection

The data collected in this study, both at IRRI ZES and in Nueva Ecija, are shown in Table 1. At the end of the harvest, during each season, rice fields that were harvested with combines at IRRI’s ZES (14.148° N, 121.267° E) were identified for mechanized straw collection with balers. Similarly, fields that were manually harvested where threshing was done with stationary threshers were also identified. Rice straws that were piled on the field were gathered using the round and square baler operated in stationary mode. The total number of bales per trial was counted, and the total weight of bales was recorded using an analog weighing scale. Collected rice straw data were expressed on dry weight basis. The dry matter content was determined by drying samples of rice straw in a standard air oven at 103 °C until there was no more change in the weight of the sample.

The amount of rice collected per unit area was based on the amount collected by the baler. To facilitate comparison across seasons and locations, the fresh rice straw yields were converted into their dry equivalent of 11% moisture content based on the study of [27]. The moisture content of rice straw (RS) at harvest was obtained using the standard air oven method. A sample of rice straw collected from the field of known weight was oven dried for 24 h at 103 °C and then reweighed [31].

| Parameter                        | Unit       | Description                                                                 |
|----------------------------------|------------|------------------------------------------------------------------------------|
| Effective field capacity (EFC)   | ton/h      | The amount of rice straw collected by the baler at every hour of field operations. |
| Fuel consumption                 | L/ton      | The amount of fuel (L) consumed by the tractor for every ton of rice straw collected in the field during the operation of the baler. |
| Labor requirement                | n° of person | The number (n°) of person(s) needed during rice straw collection with the baler. |
| Bale weight                      | kg; ton    | Weight of each bale collected in the field using the baling machine.          |
| Rice straw moisture content (MC) | %          | Amount of moisture in freshly collected straw in the field. Rice straw samples are collected in the field and moisture content was determined via air oven method. |

The amount of fuel consumed was determined by tank refill method, such that the tractor’s fuel tank was filled to full capacity before each trial, then topped up at the end of the trials and the amount of fuel consumed was measured [32]. The total time of baling operation during each trial was recorded from the start of when the tractor began operating in the field until the last baled rice straw was expelled from the machine. The amount of manpower involved in baling operations was also recorded.

2.3. Calculation of Collection Costs and Financial Analysis

The cost of mechanized rice straw collection was calculated based on the depreciation of the machine, maintenance, interest rate, fuel consumption, manpower, twine, and administrative/office expense [2] per ton of baled rice straw. The assumptions for the computation of parameters for the financial analysis are shown in Table 2, including the following: (1) 8% loan interest from agricultural banks in the Philippines; (2) maintenance coefficient of 0.5; (3) US$ conversion to Philippine peso is 50.6.
The internal rate of return and payback were the major parameters that were considered in deciding the financial feasibility of a custom service business model for mechanized rice straw collection.

Table 2. Machinery costs and assumptions used in the financial analysis.

|                         | STAR MRB0850B | CLAAS Markant 55 | New Holland BC5070 |
|-------------------------|---------------|------------------|---------------------|
| Capital Investment US$  | 8000          | 19,000           | 19,000              |
| Baler                   |               |                  |                     |
| Tractor                 | 15,000        | 20,000           | 20,000              |
| Workshop                | 3000          | 3000             | 3000                |
| Tractor power rating hp | 35            | 60               | 90                  |
| Capacity a ton/h        | 1.3–1.6       | 1.5–2.0          | 1.5–2.0             |
| Type                    | Round         | Square           | Square              |
| Estimated life years    | 5             | 5                | 5                   |
| Operation per year b    | 60            | 60               | 60                  |
| Maintenance coefficient c | 0.5          | 0.5             | 0.5                |
| Interest rate d %       | 8             | 8                | 8                   |
| Value Added Tax e %     | 12            | 12               | 12                  |

a [33]; b Based on the duration of the fallow period at International Rice Research Institute, Zeigler Experiment Station; c [34]; d The average loan interest rates computed from the interest rate charged by Land Bank of the Philippines, a government-owned agricultural bank in the Philippines that offers loan assistance to farmers through several facilities (e.g., Agricultural Competitiveness Enhancement Fund or ACEF, Agricultural Credit Support Project, etc.); e As per regulations of the Bureau of Internal Revenue (BIR) of the Philippines [35].

2.4. Data Analysis

The Statistical Tool for Agricultural Research (STAR) Version 2.01 [36] was used for designing the field experimental layout, performance of analysis of variance (ANOVA), and correlation analysis on the data gathered from Table 3.

3. Results

3.1. Field Capacity and Rice Straw Yield

The average amount of scattered rice straw collected by the round baler was 0.76 ton/ha, and the average length of rice straw in the field was 55.32 cm. The square baler, on the other hand, was able to gather 1.77 ton/ha of scattered rice straw, and the average length of rice straw in the field was 35.4 cm. This shows that the length of rice straw left over in the field did not affect the amount of baled straw that was collected. This could be because of the differences in varieties of rice that were grown in each field and some varieties being mixed in piled rice straws, which was not considered in this study. For the round baler pulled by the 35HP 4WD tractor, the rice straw (RS) yields during the dry season (DS) were 0.33 and 0.54 ton/ha, respectively, for piled and scattered rice straw, while the lengths of rice straw were 50.8 and 58.4 cm for piled and scattered rice straw, respectively. The square baler pulled by a 60HP 4WD yielded 0.60 and 1.42 ton/ha in piled and scattered rice straw conditions, and the length of rice straws in the field was 45.7 and 49.7 cm, respectively. For the wet season (WS), the rice straw yields were 0.25 and 0.97 ton/ha for the round baler in piled and scattered rice straws, and the rice straw lengths were 60.8 and 52.2 cm, respectively.

Similarly, the moisture content of rice straw does not correlate with rice straw yield in this study. The average moisture contents (MC) of rice straw during the dry season were 27.0 and 27.2%, and the average RS yields were 0.44 and 1.01 ton/ha, respectively, for the round and the square baler. In the wet season, the average MCs of rice straw were 39.0 and 39.1%, and the rice straw yields were 0.61 and 1.73 ton/ha for the round and the square baler, respectively.

The baling rate varied significantly for both the round and square balers in piled and scattered rice straw conditions. The square baler collected a greater amount of rice straw and had a higher effective
field capacity (EFC) on scattered rice straw, which is significantly different to the round baler (Table 3) at 1.90 ton/h, compared to the round baler at 0.38 ton/hr.

Table 3. Mean comparison (at α = 0.05) of different parameters during baling operations at IRRI ZES.

| Parameters/Treatments | Unit     | Round Piled | Round Scattered | Square Piled | Square Scattered |
|-----------------------|----------|-------------|-----------------|--------------|-----------------|
| Rice straw yield at 11% MC | ton/ha   | 0.29b (±0.08) | 0.757b (±0.33) | 0.53b (±0.11) | 2.21a (±0.90)  |
| RS length             | cm       | 55.74 (±6.28) | 55.32 (±5.12)  | 58.02 (±13.97) | 35.37 (±15.99) |
| Fuel Consumption      | L/ton    | 9.99a (±3.79) | 9.31a (±3.26)  | 10.63a (±3.88) | 3.83b (±0.69)  |
| Energy Input          | MJ/ton   | 447.62a (±169.59) | 417.26a (±146.06) | 476.11a (±173.96) | 171.72b (±31.03) |
| Field Capacity        | ha/h     | 0.67bc (±0.33) | 0.38c (±0.14)  | 1.19a (±0.17)  | 0.95ab (±0.37) |
| Baling rate or Effective Field Capacity (EFC) | ton/h | 0.18c (±0.05) | 0.28c (±0.14)  | 0.6b (±0.12)   | 1.90a (±0.38)  |
| No. of bales/ton      | bales/ton| 74b (±14)    | 132a (±24)    | 39c (±3)       | 44c (±13)      |
| Baling Cost           | US$/ton  | 133.00a (±31.11) | 110.64a (±46.71) | 56.55b (±10.25) | 20.95b (±4.73) |

Note: Values with the same letter in the same row indicate that the means are significantly different (p-value ≤ 0.05).

The amount of rice straw collected by the baler per unit area does not directly correlate with the length of rice straw left in the field, while the effective field capacity (EFC) correlates positively with the actual amount of rice straw collected by the baling machine per unit area (r = 0.9, p-value = 0.0000), as shown in Table 4. The EFC of the round and square balers during the DS were 0.17 and 1.18 ton/ha, respectively. During the WS, the EFCs were 0.30 and 1.34 ton/ha, and RS yields were 0.61 and 1.73 ton/ha, respectively, for the round and the square balers. Fuel consumption does not depend on the amount of rice straw collected or EFC in this study (r = −0.6842; p-value = 0.0002). This was similar to the findings of [37], which compared the specific fuel consumption of baling systems to the amount of rice straw collected.

Mechanized collection using a square baler in Nueva Ecija also showed a positive correlation between EFC and rice straw yield (r = 0.7, p-value = 0.14), but it was not significant at α = 5%. The EFCs of the new Holland BC5070 baler used in the field were 1.51 and 1.37 ton/ha, and the RS yields were 1.68 and 1.27 ton/ha during the dry and wet seasons, respectively. On the other hand, the EFC has a strong and yet inverse correlation with baling cost (r = −0.9635; p-value = 0.0020).

The conditions of rice straw for baling in the field have an effect on EFC, such that the scattered rice straw resulted in a greater number of baled straws than piled rice straw. The square baler produced an average of 44 and 39 bales/ton for scattered and piled rice straw conditions, respectively, while the round baler produced 132 and 74 bales, respectively, for scattered and piled RS in the fields. The average weights of round bales (at 11% MC) were 11.53 and 10.21 kg for dry and wet seasons, respectively. While, for the square bales, the average weights were 21.71 and 28.71 kg (at 11% MC) for the dry and wet seasons, respectively. The square bales in Nueva Ecija had average weights of 11.46 and 10.39 kg for the dry and wet seasons, respectively.

Table 4. Correlation analysis of different baling parameters at IRRI and Nueva Ecija.

| Parameter                        | Correlation to | Equation          | Coefficient and p-value at α = 5% |
|----------------------------------|----------------|-------------------|----------------------------------|
| RS yield, ton/ha                 |                |                   |                                  |
| Average                          |                |                   |                                  |
| r                               | −0.8184        | p-value = 0.0000  |                                  |
| a                                |                |                   |                                  |
| Moisture content, %              |                |                   |                                  |
| Average                          |                |                   |                                  |
| r                               | −0.145         | p-value = 0.499   |                                  |
| Effective Field Capacity (EFC), ton/ha |                |                   |                                  |
| Average                          |                |                   |                                  |
| r                               | 0.8961         | p-value = 0.0000  |                                  |
| Fuel consumption, L/ton          |                |                   |                                  |
| Average                          |                |                   |                                  |
| r                               | −0.6343        | p-value = 0.0005  |                                  |

Note: The parameters are significant at α = 5%.
3.2. Fuel and Labor Usage

The amount of fuel consumed during baling operations varied significantly for the different baling operations. The square baler consumed fuel at an average of 3.83 and 10.63 L/ton for the scattered and piled rice straws, respectively. The round baler used 9.31 and 9.99 L/ton of fuel consumption for the scattered and piled rice straw, respectively. Comparing the consumption of fuel in gathering scattered rice straws, the square baler had a significantly lower fuel consumption of 3.83 L/ton of fuel compared to the round baler, which consumed an average of 9.31 L/ton. The New Holland BC5070 baler had a much lower fuel consumption of 3.08 L/ton in gathering scattered rice straws in the field compared to the Markant 55. Fuel consumption does not correlate positively with the EFC of both machines; in fact, the relationship is opposite. This could mean that the EFC is not optimum, which is why the higher fuel consumption of the tractor would not lead to a higher output of the baler. Graphs showing the relationship between fuel consumption and baling rate show that the square baler has a lower fuel consumption and higher baling rate than the round baler, with EFC in the range of 1–2.4 ton/h and fuel consumption of about 2–4 L/ton. On the other hand, the round baler showed an EFC from 0.2–0.4 ton/h and fuel consumption in the range of 6–13 L/ton.

In all operations, the amount of manpower involved in the baling operation is 2–3 persons, which includes one operator and two helpers. It was only during the dry season in field operations at IRRI that two (2) laborers were required, and the rest of the field trials involved three (3) persons during the baling operation. The operator’s helper is tasked to haul baled straws in the field and haul them to the side of the field.

The graphs in Figure 2 show the relationship between EFC and fuel consumption (L/ton). The best fit line of EFC (Y-axis) and fuel consumption (X-axis) of the STAR MRB0850BT baler used on scattered rice straw at IRRI showed a higher correlation coefficient ($R^2 = 0.9984$) than the Markant 55 baler.
(R² = 0.8045) and New Holland BC5070 baler (R² = 0.4612), which means that the STAR MRB0850B baler performed at a lower EFC of 0.28 ton/h and a higher fuel consumption of 9.08 L/ton compared to the Markant 55 and BC5070, which performed at a higher EFC of 1.9 ton/h and 1.51 ton/h, respectively; and a lower fuel consumption of 3.8 L/ton and 2.48 L/ton, respectively.

![Figure 2. Relationship between effective field capacity (EFC) and fuel consumption of different balers used in baling scattered rice straws in the field.](image)

3.3. Baling Costs and Calculated Financial Parameters

The costs involved in the baling operations include the following—labor, fuel, twine, office, interest and depreciation, and maintenance. The STAR MRB0850B baler, when used for baling piled rice straw, incurred the highest average cost at US$124.14 per ton, and for baling scattered rice straw the cost is US$109.66. The Markant 55 baler had lower average costs of US$56.16 and US$20.66 per ton for piled and scattered rice straws, respectively. The operation of the New Holland BC5070 baler on scattered rice straw resulted to an average cost of US$26.10 per ton.

The purchase cost and basic assumptions used in calculating for financial and economic parameters are shown in Table 2. Among the cost items, depreciation and maintenance had the biggest percentage contribution, which was about 35% of the total cost of baling in Nueva Ecija. The baling operation on piled rice straw at IRRI incurred high depreciation costs of 37 and 38% for round and square balers, respectively. The depreciation cost share for baling scattered rice straw are 31 and 34% for round and square balers, respectively. The data shows that depreciation is inversely related to the effective field capacity of the machine, which means that, as the EFC increases, the depreciation and maintenance cost decreases. The round baler had an average baling rate of 0.23 ton/h as opposed to the square baler, which has an average baling rate of 1.26 ton/hr. The depreciation costs for the round baler is higher at US$39.63 per ton compared to square baler, with an average depreciation cost of US$14.28.

The cost of twine used for baling is another cost item that significantly varies with the type of baler used. The round baler had a higher usage of twine at US$12.36 compared to the square baler at US$2.48 per ton. The cost of twine is directly related to the number of bales per ton of rice straw, such that the square baler produced an average of 44 bales per ton compared to the round baler, producing an average of 130 bales per ton. Round bales also used an average length of 8 m of twine per bale compared to the square bales that used only around 4 m of twine per bale.

In a recent market study conducted in the Philippines [11,38] baling of rice straw can improve the availability of rice straw as alternative feeds to ruminants throughout the year. In the six provinces (i.e., Bukidnon, Ilocos, Iloilo, Isabela, North Cotabato and Nueva Ecija) that were surveyed in the country around 55% and 59% of carabao and cattle, respectively, are being fed with rice straw [11].
More than half of the farmers who are feeding rice straw to ruminants are willing to buy rice straw in baled form and even those who are not buying rice straw for feeds would be interested to buy baled rice straw to be used as feeds at a price of Php1.4 per kg or US$27.5 per ton \[38\]. At the ruminant farm of Philippine Carabao Center (PCC) in Nueva Ecija, there are about 700 heads of buffaloes that consume rice straw as alternative feed of around 25–50 kg per buffalo which means an average demand of 7700 tons per year but at the moment the average amount of rice straw collected per year is 2000 tons \[13\]. In a recent value chain workshop conducted at PCC in October 2019, it was revealed that the total number of ruminants (consist of cattle and buffalo) in Nueva Ecija is about 57,054 heads which would need a yearly average of 197,834 tons of rice straw when used as part of the daily recommended feed ration with 18.4% rice straw \[38\]. A farmers’ cooperative, Nueva Ecija Federation of Dairy Carabao Cooperative (NEFEDCCO) is currently selling a round bale of rice straw (~27 kg in weight) at a price of Php50 (~US$1) which is approximately US$ 36.3 per ton. At this level of baling fee, using the STAR MRB 0855 would not be able to compete due to its excessively high cost of operation.

4. Discussion

The study was conducted comparing only one type of round baler and one type of square baler with different field capacities (i.e., one is pulled by a 35HP tractor and the another by a 60HP tractor) at IRRI ZES, while the study at the farmers’ field in Nueva Ecija only looked at a square baler (i.e., pulled by a 90HP tractor) that was operated by the PCC, an agency under the Department of Agriculture. The technical aspect of the study only considered the effective field capacity and size of the 4WD tractor to compare the performance of the different balers, while the economic analysis encompasses the costs involved in the baling operations and some relevant assumptions to calculate the different financial parameters.

The rice variety was not duly considered in assessing the rice straw yield due to the mixture of varieties that were planted in the fields and in piled rice straws that were mechanically threshed. Variety is one of the factors that determine the amount of biomass residue in the field, aside from the cutting height of the stubble, which affects rice straw yield, as reported by \[7,39\]. The baling rate, which is also described as effective field capacity \[40\], is the actual amount of rice straw collected by baler per unit time. The effective field capacity (EFC) and bale weight were the major determinant factors of the amount of baled rice straw per hectare that were measured in this study. The relationship between EFC \((r = 0.90, p\text{-value} = 0.0000)\) and average bale weight \((r = 0.97, p\text{-value} = 0.000)\) and the amount of rice straw yield clearly supports this observation.

The negative correlation of rice straw length with the amount of baled rice straw \((r = −0.8184, p\text{-value} = 0.0000)\) means that a high amount of rice straw in the field is not a determinant of baled rice straw output. Several studies have reported that the amount of rice straw available for collection would depend on the cutting height of stubbles during the harvesting of the rice crop \[21,33,41\], stating that low cutting height would result to higher straw yield, and higher cutting would correspond to a low amount of rice straw being recovered from the field. Several factors could affect rice straw recovery from the field using a baler machine, which include the skill of the operator, the speed of collection, field condition, straw condition, and MC, as well as the condition of the baling machine itself. A recent study conducted by \[42\] evaluated the performance of a round baler and showed that the moisture content of rice straw has no significant effect on the baling cost, which confirms the findings in this study, as shown in Table 1.

Rice straw is traditionally gathered by hand, which is easy when threshing is done with a stationary axial flow thresher, but with combine harvested crop, rice straw collection becomes laborious and tedious and needs about 17 people to collect an area of one hectare in one day. With mechanized collection, the duration of rice straw gathering is reduced by 1 to 4 h per unit hectare, depending on the size and capacity of the baling machine used. The capacity of the baler is determined by the width of the pick-up, the baling chamber, and the size of tractor that is pulling the machine. The round baler (STAR MRB0850B) used in the experiment has a pick-up width of 0.80 m, and it has an average field
capacity of 0.38 ha/h, while the square baler (CLAAS Markant 55) has a pick-up width of 1.65 m and field capacity of 0.95 ha/h. The round and square balers differ significantly in the effective field capacity (EFC) and the amount of rice straw baled per unit time. The square baler operating on scattered rice straws showed a significantly higher EFC in two seasons (dry and wet seasons) at an average of 1.90 ton/h compared to the round baler, which demonstrated an EFC average of 0.62 ton/h. This is consistent with the findings of [32] who reported that the highest values of field efficiency were measured with the square baler because this machine ties and ejects the bale without stopping, while the round baler stops to wrap-eject the bale, thus reducing the field efficiency and consequently the actual field capacity. A similar study conducted by [2], using the same type of round baler, performed with an average collection capacity of 2.2 ton/h on scattered rice straw in the field. The big difference in the effective field capacity could be attributed to the amount of available rice straw scattered in the field owing to the variety, straw cutting height, and field conditions.

The average EFC of both the round and square balers are significantly lower for piled rice straws, at 0.18 and 0.28 ton/h, respectively. The EFC of the machines also affected directly the cost of baling because of the fuel consumed, labor required, maintenance, and depreciation. In this experiment, we found that the square baler (Markant 55), operating on scattered rice straws, is much more economical than gathering rice straws that were piled on the field. The cost of baling rice straw scattered on the field is significantly lower with the use of the square baler than with the round baler by about 4.3 times, such that the average cost per ton is US$20.95 and US$110.64, respectively. Nguyen-Thanh-Nghi et al. (2015) conducted a study on a similar model of a round baler, which showed a baling cost of US$19/ton, inclusive of depreciation, repair, labor, twine, fuel, and interest costs. The huge difference in baling cost could be attributed to the lower field capacity of the round baler that was operated at IRRI ZES (i.e., 0.38 ha/h) compared to the operational field capacity of the round baler in Vietnam (i.e., 0.5 ha/h). The lesser amount of rice straw collected on the field also affected the high cost of baling of the baler at IRRI ZES. The graph in Figure 2 also validates the high cost of operation of the STAR MRB0850B at IRRI, with it having high fuel consumption and lower effective field capacity compared to the square balers. On the contrary, [25] reported a lower production cost of round bales compared to square bales of 4%, and compared big balers (pulled by 142kW 4WD tractor) in baling sugarcane straw that used round and square balers with an area capacity of 1.84 and 2.23 ha/h, respectively.

Comparing the cost for piled and scattered rice straw conditions using the square baler, the cost of baling is significantly higher by 1.7 times for piled rice straw than for scattered rice straw. The cost of depreciation and maintenance is directly affected by the baling rates for both types of baler, given the same working days per year. The square baler operating on scattered rice straw would have lower maintenance and depreciation cost per ton of baled rice straw at US$7.07 compared to when it is operated on piled rice straw, with US$21.50 per ton. Comparing the operation of square balers at IRRI (Markant 55) and Nueva Ecija (New Holland BC5070), the Markant 55 has lower maintenance and depreciation costs by about 7%, while the effective field capacity is higher by about 26%. There is a way of lowering the cost for maintenance and depreciation, thereby lowering the total cost for baling, by having a busier operation or increasing the operation days per year and optimizing the efficiency of the baling operation and the effective field capacity.

The overall maintenance management of agricultural machines has been studied and seen to have an impact on the performance efficiency, reliability at work, and useful life of the machine [43,44]. Tractors and agricultural machines that are often excessively used in the field, neglecting the periodic maintenance, might result in lower efficiency, reduced field performance, and higher operation cost (e.g., fuel, additional labor, etc.) as in the case of the balers used in this study.

Considering the costs of operating the baler at PCC in Nueva Ecija, the IRR and PP were computed. The various costs that contribute to the total cost of baling include depreciation and maintenance, bank interest, twine, fuel, labor, and office. The sensitivity analyses shown below in Table 5 indicate that the baling service would be viable when operated at a cost between US$25–30 per ton of baled straw at the current level of effective capacity of the baler. Varying the operating days per year would
significantly increase or decrease the financial indicators (i.e., IRR and payback period) at certain levels of service fee. The baling cost would also be affected by the variability of operating days per year of the baling service.

Table 5. Sensitivity analysis at different levels of baling service fee and working days per year based on the cost of operating a BC5070 baler in Nueva Ecija.

| Service Fee (US$/ton) | Working Days Per Year | IRR (%) | Net Profit (US$/Year) | Payback Period (Years) | Baling Cost * (US$/ton) |
|-----------------------|-----------------------|---------|-----------------------|------------------------|------------------------|
| 20                    | 100                   | 19.45   | 4192.00               | 5.01                   | 17.38                  |
|                       | 120                   | 5.17    | 7142.40               | 2.94                   | 16.28                  |
|                       | 140                   | 0.32    | 10,422.72             | 2.09                   | 15.51                  |
| 25                    | 100                   | 3.86    | 12,192.00             | 1.72                   | 17.38                  |
|                       | 120                   | 8.47    | 16,742.40             | 1.25                   | 16.28                  |
|                       | 140                   | 1.78    | 21,257.60             | 0.99                   | 15.51                  |
| 30                    | 100                   | 8.72    | 20,192.00             | 1.04                   | 17.38                  |
|                       | 120                   | 5.91    | 25,342.40             | 0.80                   | 16.28                  |
|                       | 140                   | 2.17    | 32,457.60             | 0.65                   | 15.51                  |

* Baling cost considers all operating costs (including maintenance and depreciation) in using the baler to gather rice straw at farmers’ fields in Nueva Ecija.

The sensitivity analysis in Table 5 looked only at the cost of operation of the BC5070 baler used in the field in Nueva Ecija. It compared the baling costs and service fee charged in different working days of the baler in a year.

It then shows that the price of US$25 per ton is profitable when operated at no less than 93 days per year, with IRR higher than the bank rate of 8%. At this level of service fee and an average effective field capacity of 1.51 ton/h, the PP at break-even will be between 1.2–6 years and a net profit of US$4100–21,000 per year.

Service fees can be increased up to US$30 per ton, which is still below the prevailing service fee being charged by only a few farmers’ groups who are operating rice straw balers in the province. At this level, the custom service business remains profitable, even when operated at 60–90 days per year. Martelli et al. (2015) cited that the lifespan of the machine could be depleted throughout its economic life, with annual usage being completely maximized. So, for financial consideration, it would be safe to consider the feasibility of the custom service business whenever PP is below the indicated lifespan of five years.

The sensitivity analysis in Table 5 clearly indicates that charging a service fee of US$20 per ton in baling rice straw would still be feasible as long the operating days per year are ensured to not fall below 120 days. There could be options for the equipment owner to use the tractor for other services, such as for land preparation, hauling, etc., to completely maximize the annual usage without negatively affecting the operating cost.

The results presented in this study can be replicated in other parts of Asia where collection of rice straw after combine harvesting is a major issue and alternative uses are lacking for sustainable rice production.

5. Conclusions

This study has shown that collection of scattered rice straw on the field can be made more efficient with the use of rice straw balers. The use of a square baler with at least 1.65 m pick-up gatherer, pulled by a 60hp 4WD tractor, can collect at higher capacities on scattered rice straw at a rate of 1.9 ton/h, while a round baler with a pick-up width of 0.8 m pulled by a 35hp 4WD has an effective field capacity of 0.62 ton/h. The cost is significantly lower for the square baler by 4.3 times, which is US$20.95 and US$110.64 per ton, respectively, for square and round balers. This indicates the suitability of using a square baler under the conditions found in the Philippines. Given the average effective field capacity
of the square baler in Nueva Ecija, a custom baling service at a rate of US$25–30 per ton would be viable if it is operated for 60–100 days per year. By employing sensitivity analysis, the baling cost can be lowered by increasing the annual usage of the machine, thereby optimizing the field capacity of the balers. With the increasing demand for rice straw as feedstock for ruminants and other alternative uses, the use of balers to collect rice straw in the field is a sustainable option for farmers in Nueva Ecija. A much more detailed adaptive study at the farmers’ field is recommended in order to gather relevant data on rice straw yield from the different rice varieties grown by farmers, as well as data on varying field conditions, to document their effect on field capacities and the cost of baling. This could be utilized as a guide for decision-making to support the viability of custom service provision on mechanized straw collection. The height of stubbles, length and amount of rice straw are some specific parameters that can be measured in the field prior to baling which can be related to rice straw yield per hectare. The size and capacities of other baling machines at the farmers’ field can also be considered in analyzing the viability of custom baling service business model.

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